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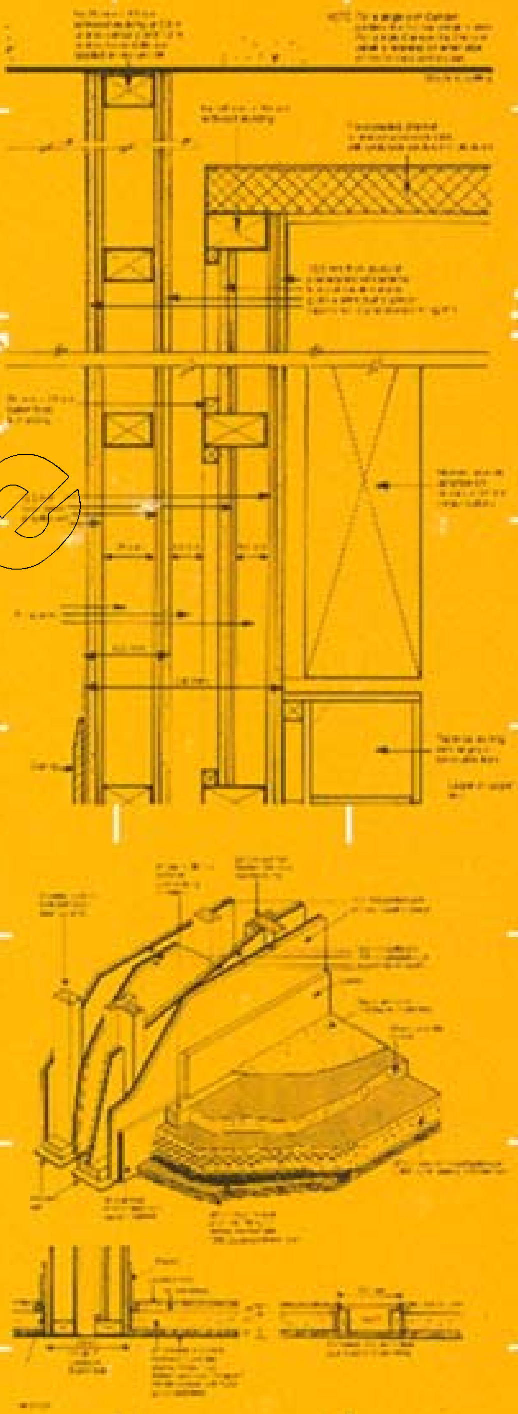

Guide to Acoustic Practice

2ND Edition

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BBC ENGINEERING

Architectural and
Civil Engineering Department

Guide to Acoustic Practice

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Issued by:
R.J.A. Fowler Dip. Arch R.I.B.A.
Head of Architectural and Civil Engineering Department

Prepared by:
Keith A. Rose, R.I.B.A.,F.I.O.A.
Acoustic Architect, Architectural and Civil Engineering Department

The author wishes to acknowledge contributions from many BBC colleagues particularly:-

D.J. Meares, B.Sc.(Eng),C.Eng.,M.I.E.E.,F.I.O.A.
Head of Sound Section, Research Department

R. Walker, B.Sc.(Eng),C.Eng.,M.I.E.E.
Senior Research Engineer, Sound Section, Research Department

A.R. Woolf, M.I.O.A.
Acoustic Engineer, Resource Development and Engineering, Radio

A.A. Fullerton, B.Sc.(Hons),Dip.Arch.,R.I.B.A.
Associate Architect, Architectural and Civil Engineering Department

P.L. Jeffree, B.Sc.(Hons),Dip.Arch.
Associate Architect, Architectural and Civil Engineering Department

A.C. Reid, M.C.I.B.S.E.,
Associate Mechanical Engineer, Architectural and Civil Engineering Department

R.M. Cole, B.Sc.(Hons).
Acoustic Specialist, Architectural and Civil Engineering Department

Photographs by:

Des Hill, Architectural and Civil Engineering Department

INTRODUCTION

The Guide to Acoustic Practice originated in 1971 when the then BBC Acoustic Architect, the late Sandy Brown, recommended that a site instruction document on acoustics be drawn up for the BBC clerks of works.

From that original recommendation the Guide developed into the 37 page first edition which was produced in 1975 as a BBC in-house document for architects, mechanical and electrical engineers, clerks of works and others involved in the design and construction of BBC studios.

In 1980 a more extensive second edition was produced for public use but still retained the BBC in-house flavour.

The Guide to Acoustic Practice was written to ensure that all those involved in studio design and construction were fully aware of the acoustic standards expected in the fabrication of studios.

This 1990 edition is a reorganised and extended version of the previous edition with a number of sections and acoustic data added. One particular change is that the main text has been grouped into the three categories in which studio acoustic surveys are conducted by acoustic consultants, namely Noise, Sound Insulation and Room Acoustics.

Although the Guide to Acoustic Practice is primarily intended for those involved in the broadcasting industry it has been written as a document for all to read and digest. Its aim is to help acousticians and others in the building industry to ensure that buildings can be used for their intended purpose without having to suffer from acoustic defects which were avoidable at the design stage.

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SECTION 1 NOISE

ILLUSTRATIONS

1. NOISE

1.1 Planning for Quiet

Good acoustic planning can dramatically reduce construction costs. This is particularly important in the design of broadcasting buildings where the studios themselves require exceptionally low internal background noise levels. For reasons of convenience or access, studio centres are often required to be sited close to a city centre or other noisy environment, rather than on a quiet green field site which would be far more suitable acoustically for a studio centre than a site surrounded by major roads. The planning and structure of the building must therefore be carefully designed to provide maximum attenuation of noise into the studio areas. It should be noted that any extraneous noise will be picked up for broadcast by a studio microphone, giving rise to complaints from listeners or viewers. Alternatively it can cause expensive retakes of recorded programme material. The use of studios as sculptural blocks in an architectural composition, placed either in the foreground of a complex or rising from a low level platform may look aesthetically pleasing but can result in the studio walls and roof being subjected to high levels of noise particularly from road, rail, helicopters and other civil or military aircraft. Before design work commences it is essential to carry out a one-third octave analysis of the airborne and ground borne vibration levels on the site. This survey should record the maximum airborne and vibration noise levels. The layout and structure should then be designed to exclude these maximum noise levels from any area requiring quiet conditions.

Noise surveys resulting in single figure values, such as dBA are not suitable for this type of building design as they provide insufficient detailed information regarding the frequency distribution of the noise and consequently are virtually impossible to relate to building product performance data.

Traffic noise from heavy goods vehicles or buses can produce airborne noise levels well in excess of 95 to 100 dB at low frequencies. These can lead to the excitation of structure borne vibrations with resultant effects on studio microphones and other noise-sensitive technical equipment. To reduce these to an acceptable level within a studio it could prove necessary to use triple masonry or concrete structures with the actual studio formed as a fully floated box within a box. However if the studio areas are screened from the traffic noise by other less noise sensitive areas then double-skinned structures may suffice. In acoustic terms it is basic common sense to enclose all noise sensitive areas within areas that will accept higher noise levels such as electronic maintenance or test rooms, offices etc. This concept, which was first introduced by the BBC in the late 1920's when Broadcasting House was originally planned with its central core of studios on alternate floors surrounded by corridors and offices, is even more relevant today.

Mechanical workshops, stand-by diesel generators, refrigeration machines, boilers and other heavy machinery or operations should all be sited as far away as possible from noise sensitive areas as all are capable of producing high structure borne noise levels in addition to their high airborne noise levels. Experience has shown that they should be sited at the lowest level in the building so that the necessary anti-vibration measures can be taken, or alternatively located in a separate plant building.

External noise breakout from all plant or equipment, bearing in mind background sound levels at the site boundary or nearest residential property, must be taken into account at the design stage. (See also Section 1.4).

Air handling units or individual fans should both be located away from but sited reasonably close to the areas they serve. This is an important acoustic design consideration as the siting of fans a considerable distance away makes it extremely difficult to provide the desired background noise level in the studios they serve with the results being generally too quiet as a result of the long duct runs. This may appear to be a contradictory statement, but the BBC noise criteria curves are designed to provide a masking background noise level matched to a building insulation specification. If the achieved noise level

is excessively low then the sound insulation will need to be increased by a corresponding amount otherwise complaints of "poor sound insulation" will arise from studio operators as sounds normally masked by the ventilation noise become audible. It should be noted that a 5dB increase in the sound insulation requirement could result in the mass of a studio structure being doubled with consequent increases in building costs.

The requirement for inter-office privacy often causes major problems for the designer when induction units or other perimeter air handling devices are installed in management and production offices. Unless there is careful co-operation between the client, the air-conditioning engineer and the architect at the design stage, inter-office sound insulation can be considerably degraded by noise transfer between areas via the units. It is imperative that partitions requiring good acoustic performance should be sited on columns and that they are not by-passed by the units, otherwise the sound insulation will be limited by the ineffective pugging of the interior of the induction unit. The above comments also apply to possible noise transfer between areas via ductwork and penetration for cables and pipework. It is also essential that all such partitions are carried up to the underside of the structural slab above to ensure acoustic integrity.

Preformed external wall cladding which incorporates services or service ducts can also provide a route for noise transfer from one area to another when the cladding panels are fixed to the external face of the columns.

1.2 Site and Construction Noise

Disturbance caused by noise from construction sites and from general building operations can be divided into two basic categories

(i) Construction noise or noise from building operations which can affect neighbours.

(ii) Noise from building operations which can affect the occupants of the building itself or its operation.

1.2(i) Construction noise or noise from building operations which can affect neighbours.

1.2(i)a Construction Noise

Noise control on construction and open sites is controlled by British Standards (BS 5228 Parts 1 and 2 1984) and other legislation operated by the local authorities who can impose limits on the maximum noise levels that may be generated on a building site. These limits are sometimes conditions of the Planning Consents granted by the local authority.

Although construction and demolition operations only last for a comparatively short period of time they are generally carried out in the open air and the resultant noise levels can cause disturbance to the occupants of neighbouring properties. This is particularly noticeable where there are high rise buildings adjacent to the site and the noise is reflected off their facades.

Noise levels from construction sites can generally be reduced by one or more of the following four means.

(i) Distance. Increasing the distance between the noise and the receiver is considered to be the most efficient means of reducing noise from an open construction site. This is based on the fact that each doubling of the distance between the noise and a receiver can give a reduction in noise level of 5dB or more depending on the terrain and prevailing weather conditions.

Noisy equipment such as compressors or generators should if possible be located away from any noise sensitive areas to reduce the level of possible annoyance.

(ii) Reduction of noise at source. This is one of the most important factors in the reduction of noise from a building site.

Compressors, generators and other noisy machinery should be provided with acoustic enclosures or hoods designed to enclose the machine as fully as possible, with particular emphasis on noisy components. The structure enclosing the machine should have adequate sound insulation properties, particularly at the frequencies at which the machine produces maximum noise. The enclosure should be lined

internally with absorbent material to reduce the reverberant noise level within the enclosure.

Because openings are required in enclosures for access or ventilation and such openings allow some egress of noise, it is generally sufficient for the enclosure to have an average sound insulation value of approx. 25dB to 30dB.

(iii) Screening of the site, or sections of the site where noisy operations are likely to occur can help reduce annoyance to neighbours. Substantial hoardings, earth mounds, site huts or even siting of building materials can all be used as screens. The effectiveness of any noise barrier depends on its length, effective height, and its position relative to the noise source, the receiver, and any reflective surface adjacent to the site.

(iv) Selection of quiet building techniques. Some processes, for example pile driving and compaction generate high levels of both airborne noise and ground borne vibration which can appear as noise in buildings a considerable distance from the site. The airborne noise itself may possibly be acceptable but the structure borne noise often gives rise to worries that the vibration may be damaging to property. In the case of broadcasting centres, such vibration can cause damage to recording heads or similar broadcasting or recording equipment and therefore such levels must be avoided at all costs.

Piles can be bored rather than driven, which is a good example of noise reduction by the use of quieter building techniques. Even with bored piles it is necessary to ensure that pile casings are not withdrawn using vibratory techniques which can cause high vibration and airborne noise levels. One solution to this problem is to use pile casings which can be left permanently in the ground. Alternatively auger bored piles can be used with the concrete pumped in under pressure as the auger is withdrawn.

Simple changes to normal constructional methods can also reduce the overall noise levels and these include the use of screws instead of nails, the use of sharp saws and drills and the careful handling of building materials such as scaffolding tubes.

The above statements all refer to construction work carried out mainly in daytime; work carried out at night generally causes more disturbance and consequently local authorities apply more stringent noise level limits and in some instances impose a total ban on operations such as percussion piling at night.

1.2(i)b Typical Contract Statement on Building Site Noise Control

As a guide to the limit of noise that is considered to be acceptable in London the following statement was included in the contract documents for a large BBC studio development which has residential properties along one boundary.

"The Contractor shall take note that the existing television and radio studios will be in occupation throughout the contract and that the whole of the works shall be executed in such a manner as to cause no interruption of the employer's business, and to reduce inconvenience, discomfort, noise and permeation of dust and dirt to a minimum.

All internal combustion engines used for the Works, whether to drive plants at the site or in transport vehicles shall be fitted with efficient suppressors in the ignition system in accordance with the recommendations of B.S. 833 so as to prevent electrical interference to radio or television receiving apparatus in the vicinity. All temporary electrical installations such as motors or the like shall be prevented from creating such interference and the Contractor will be responsible for fitting suppressor equipment in accordance with B.S. 613 as directed by and to the satisfaction of the engineer.

The Contractor shall take note that electric and welding equipment may cause interference and he shall therefore consult with the employer before attempting to utilise any apparatus of this nature. Any enforced cessation of work will be paid for as described in the next item. Whenever possible, noise from compressors and other plant shall be muffled by silencers, screens and other means to reduce airborne sound to a minimum.

The Contractor shall carry out the works (which may be in progress at the same time as the testing of electrical apparatus and/or recording and rehearsals in the radio/T.V. studios in the vicinity), with as little noise as possible and no nuisance is to be caused to the employer. The employer undertakes not to bring any claim against the Contractor under this clause, but should the Employer require the contractor to desist in any operation the Contractor is to cease work immediately and is not to resume that section of the work until he receives further instructions from the engineer.

At such time, stoppages must be verified by the engineer and the Contractor will be paid for standing for men and plant used on that part of the works from the time of cessation until resumption at the rates included in Section C provided that it is impracticable for such men to be redeployed and engaged on another section of the works.

As a guidance to tenderers it is suggested that airborne noise in excess of 95dBA at any exterior wall of the existing broadcasting building or vibration velocity level exceeding 0.3 mm/s (peak) measured on the internal surfaces within the existing building are likely to cause disturbance.

Stoppages caused by airborne noise in excess of 100dBA will not be paid for and the Contractor shall provide and maintain portable sound monitoring equipment on site to enable the degree of sound responsible for the stoppage to be determined.

The Contractor shall note that the Local Authority does not permit percussion piling work to proceed at night.

The sound monitoring equipment shall comply with IEC 179/1973 Class 2 and be calibrated according to manufacturer's instructions whenever the instrument is used. Notwithstanding the foregoing the Contractor shall comply with the following Schedule of Local Authority conditions:-

1. The Contractor shall employ the "best practicable means" as defined in the Control of Pollution Act, 1974 to minimise noise and vibration resulting from his operations and shall have regard to British Standard B.S. 5228:1975 (Code of Practice for noise control on construction and demolition sites), and in particular:-

   (a) the Contractor shall ensure that all vehicles, plant and machinery used during the operations are fitted with effective exhaust silencers and that all parts of such vehicles, plant and machinery are maintained in good repair and in accordance with the manufacturers' instructions, and are so operated as to minimise noise emissions;

   (b) only "sound reduced" compressors or other alternatives approved by the Local Authority are to be used, and any equipment or panel fitted by the manufacturer for the purpose of the reduction of noise shall be maintained and operated so as to minimise noise. Any pneumatically operated percussive tools shall be fitted with approved muffles or silencers which shall be kept in good repair;

   (c) machinery which is in intermittent use shall be shut down in intervening periods of non-use or where this is impractical, shall be throttled back to a minimum.

2. Before the commencement of the works or of any significant phase thereof or immediately any change in the method of working not previously notified is effected, the Contractor shall inform the Local Authority.

3. Without prejudice to the generality of the foregoing, the following noise limits shall apply:-

   The neighbourhood noise as defined in B.S. 5228:1975 and measured in accordance with Appendix E thereof at a point one metre from the facade of the noise sensitive buildings defined below shall not exceed an equivalent continuous sound level (Leq) of:-

   (i) 80dBA on any day between the hours of 0800 and 1800.

   (ii) 60dBA on any day between the hours of 1800 and 2200.

(iii) 50dBA on any day between the hours of 2200 and 0800.

4. Notwithstanding any of the foregoing clauses, no impact piling shall be carried out except with sound reduced equipment of an approved type.

5. Blasting shall not be permitted at any time.

6. Nothing in this consent/notice shall be taken as preventing or prohibiting the execution of works which are absolutely necessary for the saving of life or property or for the safety of the works".

1.2 (ii) Noise from building operations which can affect the occupants of the building itself or its operation.

Demolition or alteration work to the fabric of the building within existing studio premises almost invariably generates structure-borne noise problems which can cause disruption to programmes being recorded or transmitted. This unwanted sound can be picked up and transmitted to the audience via the studio microphones unless careful precautions are taken to limit the noise so that it only occurs outside broadcasting periods.

Where the building work requires cutting of holes in existing brick or mass structures, or other especially noisy operations, estimates should make allowance for the work to be carried out partially or wholly outside normal broadcasting hours.

Framed building structures, particularly those constructed in steel, transmit sound energy to such a degree that in one BBC centre it has proved to be necessary for all major alteration work to the structure to be carried out between the hours of 2 a.m. and 6 a.m., otherwise all of the studios within the studio centre, none of which are resiliently separated from the main steel framework, would be affected by structure-borne noise.

Such noisy building work must be clearly identified before the commencement of a project and a detailed work programme agreed in advance with the studio operational staff to avoid noisy operations coinciding with broadcasts or recordings.

These studio operational periods should then be officially classified as "No Knocking" periods during which only quiet building activities may be carried out.

The use of some of the quieter building techniques listed earlier are particularly useful in helping to resolve this problem.

1.3 Mechanical Services

1.3 (i) Introduction (Figures 1, 2, 3 and 4)

This document is not intended to be a comprehensive design guide for mechanical engineering services being intended only to highlight those areas which frequently give rise to acoustic problems in broadcasting premises.

In the design of an air-conditioning, heating, ventilation or plumbing system for use in a Radio or Television complex, acoustic performance is a major factor influencing the overall design. Information on the acoustic behaviour of all components in the system should be taken into account in the design to achieve specified noise levels.

Acoustic specifications and measurements should be based on one-third octave bands wherever possible as this provides a more detailed specification or analysis of any noise measurement than octave data.

1.3 (ii) Background Noise Criteria

Over a period of years the BBC Research Department has, in conjunction with other specialist departments collected together all relevant information on acceptable noise levels in studios and technical areas and in 1980 published the noise criteria shown in figure 1. These are applied to all new studio installations. Any departure from these criteria has to follow a specific decision by the client or the relevant BBC Project Department for a particular project. The noise criteria known as, (i), (ii) and (iii), are for the maximum tolerable background noise levels in studios and technical areas from ventilation sources alone. They take into account the fact that since the introduction of an earlier set of

criteria curves, at least 19 years previously, other links in the broadcasting chain have been improved with regard to the signal to noise ratio. For example electronic noise reduction techniques had been introduced on tape recorders, broadcasts were more commonly listened to on V.H.F. and digital techniques are steadily being introduced, all of which required a quieter environment than the previous criteria provided.

Noise Criteria (NC) or more commonly Noise Rating (NR) curves are used for noise specifications for areas other than those specified in figure 1 and these are shown in figures 2, 3 and 4. The NR curves are an International set of Noise Rating curves, laid down in I.S.O. Recommendation 1996, which are used to provide a single figure rating of any noise measurement and to compare disturbances by noises of different spectral compositions. They are also useful if measures to reduce a noise nuisance are to be evaluated. The Noise Criteria Curves were developed by Leo Beranek in the United States of America to provide general comfort specifications. The contours of the N.C. curves were derived to express the background sound levels observed in loudness and speech interference studies in a large number of areas.

The BBC has based its criteria for sound insulation between studios and other technical areas on the assumption that the maximum permissible background noise criteria are adhered to, within the specified tolerances. (Permissible tolerances to the Background Noise Criteria are detailed in Section 1.3 (iii)). The background noise level from the ducted air system provides a defined amount of masking of extraneous noise from adjacent areas. If the overall background noise level were to be substantially lower than the criterion, then the extraneous noise normally masked by the ventilation noise would become apparent and potentially annoying to the users of the areas. If this occurs then it may be possible to increase ventilation noise to approach the criterion at certain frequencies either by increasing the airflow velocity, by speeding up the fans, closing down of dampers or by the introduction of obstructions or restrictions in the airflow such as perforated plates. Such measures are not always possible or desirable and do not always provide the appropriate spectrum shape which approaches the criterion at all frequencies. A more desirable method of achieving the criterion match is through careful ventilation system design utilising ductborne fan noise to generate low frequency sound levels and airflow effects to generate mid and high frequency sound levels. Such an exercise would involve the judicious choice of primary and secondary system attenuators and final duct airflow velocity. An alternative could be to introduce electronic masking noise, filtered to match the criterion, with loudspeaker units placed in the ceiling void or similar concealed positions. It is essential with this electronic system that the controls are linked to those of the ventilation system and are securely locked away from amateur tweakers.

If none of the above solutions are feasible then it will be necessary to increase the sound insulation of the partition or structure, if possible. This will result in additional buildings costs and disruption to often completed areas, so it is important to avoid such work if possible. It is very important to achieve the correct level of background noise in the first place.

Many broadcasting organisations throughout the world insist on a criterion similar to that of the threshold of hearing for the maximum permissible background noise level in all their studios. Such a criterion is much stricter than that specified by the BBC. The fact is that there are often unavoidable background noises from sources within the studio such as movement of actors, cameras etc., and the BBC has relaxed their noise criteria accordingly to take this into account. Therefore, it is all the more important that the above criterion curves should be achieved and no further upward relaxation permitted without the authority of the client or the relevant Projects Department.

1.3 (iii) Criterion Tolerances

A review of tolerances for the BBC noise criteria, introduced originally in 1984 by the Acoustics Committee, together with a reappraisal of the practical implications of achieving them, has led to a revised set of tolerances being introduced in 1987.

At the time of writing this Guide these tolerances apply to most projects.

These are as follows:-

(a) Programme Areas

The permitted tolerances for areas in which programme making or critical assessment of sound quality are carried out (these include all areas covered by criteria (i), (ii) and (iii), by criteria derived relative to them or other critical area criteria as specified) are as follows:

Overall

The average of the measured sound pressure levels in every frequency band shall fall within a range which is +0 to -10 dB relative to the specified criterion. This average shall be derived from recordings taken at a minimum of 5 differing microphone positions within the area being measured.

Position

No individual microphone position shall give a measured sound level at any frequency more than 5 dB above the average value for the whole room at that frequency.

Should any individual recording contain a level in excess of the overall average for the room at that frequency, it will be necessary to investigate the source of the noise and undertake remedial treatment.

Time Variation

There shall be no significant variation of the noise level over short time periods. This requirement shall be deemed to be satisfied if there is a maximum variation in noise level of less than 5 dB for all normal operating conditions.

Uniformity

In the average results there shall be no one-third octave band value which exceeds the numerical average of the two adjacent band values by more than 5 dB.

Although the formal criteria are limited in scope to the frequency range 50 Hz to 4 kHz, there are mandatory limits for the permissible levels outside that range:

Low Frequencies

For the one-third octave bands of 40 Hz and below the average noise level in each band should not exceed a level which increases at a rate of 4dB per one-third octave frequency band from the specified criterion value at 50 Hz.

High Frequencies

The average noise level in each one-third octave frequency band should not exceed that specified by the criterion at 4 kHz for criteria (i) and (ii) and 2 kHz for criterion (iii).

It should be noted that these permissible background noise level criteria refer to continuous broad band noise. It is known that intermittency or a recognisable tonal characteristic (e.g. whine, screech, squeal, hum etc.) render a noise much more noticeable, and therefore annoying, for a given sound level. It is usual to require that noises showing any of these characteristics should be reduced to 5 dB below the continuous masking noise. For example noise from lifts will normally fall into this category.

(b) Non-programme Areas

The non-critical areas have no lower limit to the permissible noise levels. The tolerances for these areas are simply that the average sound pressure level in every frequency band shall not exceed the specified criterion.

1.3 (iv) Air Systems

Noise sources in air systems can be divided into three categories according to how the noise from these sources reaches the areas which the ventilation system serves. These sound transmission paths are illustrated in figure 5.

1.3 (iv) a.

Noise transmitted from sources external to the building via the ventilation system.

External noises such as those from motor vehicles or aircraft can enter studios via the ventilation system unless precautions are taken against it occurring.

There are two routes by which these noises can enter the building. Firstly, via the air intake and extract outlets and secondly, via lengths of ducts which may appear externally e.g. on the roof of a studio.

The first problem can be eliminated by the provision of sufficient attenuation at the inlets and outlets in the form of silencers. The second one requires that any duct appearing externally must be encased in a structure similar to that which it is bypassing, e.g. if a duct runs along the top of a 60 dB roof and drops through into the studio below then the duct itself must be encased in a construction to give 60 dB attenuation. Alternatively an attenuator should be fitted where the duct passes through an external wall or roof, such that the total attenuation matches that of the structure i.e. attenuator + casing of duct = wall or roof insulation. The attenuator itself must also be encased to avoid bypassing the system.

Precautions, usually in the form of external lagging, should also be taken to prevent rain or other impact noises impinging on the external surfaces of external ducts and being transmitted into noise critical areas via the duct system.

An important point which must not be overlooked is that noise from the ventilation plant must not cause annoyance to inhabitants in neighbouring buildings, nor to occupants of adjacent areas within the same building as the plant is sited, via windows etc. Attenuators on the intake and extract ducts must be selected and positioned to stop noise getting out as well as in. (See para 1.4 for recommendations on this point).

1.3 (iv) b. Noise transmitted through or along ducts from internal sources. (Figure 5)

Noise such as:-

(i) Mechanical noise from fans, motors etc.

(ii) Self-noise due to air motion and turbulence within the distribution system.

(iii) Crosstalk between rooms via ductwork.

(iv) Noise and vibration transmitted through duct walls.

(i) Mechanical noise from fans, motors etc.

Fans are often the major source of mechanical noise in any ventilation system especially at low frequencies and will generally determine the eventual noise level in the studio and how much attenuation is required to meet a specific noise criterion.

The intensity and character of the noise varies not only with the size, speed and load of the fan, but also with the type and manufacture. Variable speed controls can sometimes be used to advantage in certain applications to reduce noise levels. It should also be noted that an unbalanced fan can aggravate the situation and may also generate structure borne vibrations.

In simple building terms, ventilation plant is capable of producing high noise levels and should be enclosed in a solid plantroom structure to reduce the radiated airborne noise. Holes through the structural walls, floors and ceilings should be avoided unless absolutely essential and all gaps around ducts, pipes etc. must be sealed with cement mortar, mastic or material of similar mass to the wall or structure. Alternatively, if the possibility of structure borne transmission of vibration exists then the pipes should be resiliently sleeved. Any duct passing through a wall or structure into a quiet area should include a crosstalk attenuator at the point where it passes through the wall or structure, as covered in section 1.3 (iv) b (iii).

In a situation where a duct passes through a wall only a few centimetres below the roof or ceiling slab, it is extremely difficult to seal around the duct. Great care has to be taken with the detailing at the design stage and close liaison must be maintained between the ventilation engineer, the clerk of works and the contractor during the construction

and installation period. (see Section 2.11 and figures 30, 31 and 32).

Plenum chambers are generally treated with sound-absorbing material to reduce the reverberant noise level. The material should be thick enough to provide the absorption at low frequencies. In most systems, however, it remains necessary to introduce silencers that are specifically designed to reduce airborne noise. They may range from a simple lining of porous absorbing material, to the use of complex resistive and reactive elements.

Over recent years it has been found that a duct system lined throughout with a porous lining usually results in the final noise level being well below the specified noise criterion, particularly at mid and high frequencies due to the significant attenuation provided by the duct lining. However without an internal lining of any sort the ventilation duct becomes a resonant cavity which is easily excited by live or reproduced speech or music generated in the studio or technical area being served by the duct. Experiments have shown that it is essential to line the ductwork internally with approved fabric faced, resin-impregnated sound absorbent material generally in the form of 150 Kg/m^3 density glass fibre or mineral wool, for at least one metre back from each grille or outlet to eliminate this resonant condition. The lining must be mechanically fixed to the ductwork. It has also been found that it is extremely important that the attenuation provided by this section of lining be taken into account in the acoustic design calculations for the overall ventilation system.

(ii) Self-noise due to air motion and turbulence within the distribution system.

Self-noise is generated by air travelling through the various sections of a distribution system. In general it can be said that air flowing around, or against bends, transitions or any object placed in the air flow, whether it be a damper, splitter, diffuser, grille or heater battery is a potential source of noise turbulence. Dampers or heater batteries in ductwork serving noise critical areas must always have secondary attenuators placed roomside of them to control airflow noise. No dampers should be included on diffusers or grilles. Generally though with good design and low airflow speeds there are no real acoustic problems. However, with medium/high velocity systems much greater care must be taken with the design to avoid obstructions. Care must always be taken in the selection of ventilation grilles to ensure that they do not rattle or resonate when excited either by the air flow or by sound from musical instruments or loudspeakers. This latter point is sometimes overlooked in the quest for the ideal and the most cost effective airflow distribution. Consequently, lightweight undamped grilles or outlets have been introduced into studios or cubicles with the result that they resonate and have to be removed and either damped or stiffened before being accepted. This can apply to both large and small grilles or outlets.

The ideal grille should be sufficiently self damped for none of the sections to readily vibrate. This can be obtained by either the introduction of damped stiffeners behind the vanes or by damping of each section or vane with damping tape or other suitable damping material, or by a combination of both techniques.

(iii) Crosstalk between rooms via ductwork. (Figure 6)

The design of a ventilation system should ensure that no flanking paths are created by the installation. Noise generated in one part of a building should not be transmitted to another, either by pick-up and re-radiation of the noise through the duct walls, by transmission from room to room through the grilles and ducts, or by direct paths through holes around the outside of the ducts. A grille or opening not only permits air and noise to enter a room, but it also allows sound from the room to enter the duct system. Thus, the opening becomes a noise source when viewed from some other part of the duct system.

To overcome the problem of crosstalk interference, an attenuator should be installed where a duct passes through a wall or floor and selected so that the sound insulation performance of the weakest part of the section of the partition through which it passes is not significantly reduced. If a door is sited in the same section of wall then the sound insulation of the attenuator should relate to the door performance rather

than the wall performance. This is illustrated in Figure 6 which shows a plan of a typical studio ventilation system which incorporates crosstalk attenuators. The attenuators in the ductwork passing direct from the corridor into the five small studios should be designed so as not to degrade the sound insulation performance of the double wall construction. In contrast those through lobbies or over doors should be designed so as not to degrade the sound insulation performance of the acoustic doors. The above statement is made with the proviso that the total attenuation provided by the primary and secondary silencers is sufficient to attenuate ventilation plant noise.

It should be noted that if duct walls were to be substantially increased in mass or lagged acoustically then the insulation required by the crosstalk attenuator could be significantly reduced and in some situations the need for such an attenuator could be eliminated altogether, provided that there are no grilles or openings in the ducts in the rooms either side of the partition.

Where a fire damper has to be provided within a duct where it passes through a wall the cross talk attenuator should be positioned as close as possible to the wall and any exposed ductwork between the attenuator and the wall should be externally clad or lagged with materials consistent with the overall crosstalk sound reduction requirements.

Additional attenuation can also be obtained by the provision of an acoustic tile ceiling suspended below the ductwork. The degree of insulation provided is dependent on the weight of the tiles. (See Section 2.5(iv)).

(iv) <u>Noise vibration transmitted through duct walls.</u> (Figure 7)

The transmission of noise through duct walls varies with frequency and with duct size, shape and materials. Rectangular or flat oval ductwork should not be used for high velocity systems as they can generate low frequency rumble. Duct walls may resonate at certain frequencies and act as new sources of noise when the vibrational energy is converted back into sound at remote points. This can be eliminated by the provision of an efficient duct lining or by adding vibrational breaks, resilient supports or damping compounds to the external duct surfaces. Figure 7 illustrates typical details for supporting ductwork where resilient supports are required.

Further reduction may be obtained by 'boxing in' the duct with Camden or similar partitioning, (See Section 2.3(ii) for details) however this can lead to unacceptable bulkheads being present in studios or cubicles which can give rise to 'honking' or other undesirable acoustic effects within the room. In the case of a control cubicle such a bulkhead if not correctly located can distort the stereo response from the loudspeakers and therefore a flat ceiling is recommended.

In circumstances where a bulkhead is unavoidable, a possible and less space consuming alternative solution to the problem is to fix carpet directly onto the duct casing, using a suitable contact adhesive.

1.3(iv)c.

<u>Machine vibration transmitted through building structures.</u>

Connections between the building structure and equipment with moving parts are obvious routes for the transmission of vibrations which can have four basic effects. Firstly, they could cause damage to the structure; secondly, they could annoy the occupants; thirdly they could interfere with work e.g. causing movement of microphones, tape recording heads or other sensitive equipment and finally they can regenerate structure borne noise as airborne sound at remote locations in a building.

Little can be done to reduce vibration of proprietary ventilation plant at source by the adjustment of the equipment itself although an imbalance in a fan, can cause a significant increase in source noise. The main effort therefore is concentrated on reducing coupling to the structure by the use of resilient materials.

The fan and its driving motor should preferably be mounted on a concrete slab, which weighs at least as much as the equipment it carries. The concrete slab itself is normally supported on rubber mats or pads, or on metal springs, to reduce vibrations being transmitted to the supporting structure. Alternatively, the

anti-vibration mountings can be placed between the equipment and the concrete base. Either system must have a resonant frequency not greater than 10 Hz. After installation the anti-vibration mountings must be checked carefully to ensure that they are working correctly, that they have not been tightened down too much, and that they are correctly loaded.

Packaged air handling units often incorporate internal anti-vibration mountings between the fan and the unit casing. Care should be taken to ensure that these springs meet the isolation efficiency requirements. Where it is decided to use external anti-vibration mounts for such systems the internal mounts should be removed or shorted out to avoid 'double resonance'.

Fans which have been placed on anti-vibration mountings must be de-coupled from any ductwork by the introduction of flexible connections manufactured from a material that complies with the local fire regulations etc.

Other examples of mechanical equipment which contribute towards overall structure borne or airborne noise problems are refrigeration machines, boilers, compressors, sprays, pumps, cooling towers and air cooled condensers. In the case of large refrigeration machines, boilers and pumps it is advisable to install them either in a separate building well away from noise sensitive areas or in a well constructed basement.

All ductwork and pipework serving moving plant must have flexible sections and be supported with resilient hangers, or off legs incorporating anti-vibration mountings, to prevent transfer of vibration into the structure. It is important to check that the hangers are capable of carrying the load of the pipework when full without suffering any undue distortion, and also that the hangers are correctly aligned, as it is possible for some types to make metal to metal contact, consequently bridging the resilient elements, if they are incorrectly installed.

Additionally flexible joints are often used between ducts and diffusers for convenience, to provide acoustic breaks.

It is extremely important that any bridging across a resiliently mounted system be avoided as this would 'short circuit' all the good work done. This is commonly the result of work carried out by following-up trades who are liable to:-

(i) Cast concrete across or up to resiliently mounted concrete bases, covering up the resilient layer.

(ii) Build walls or partitions up to, around, or even braced off, structurally isolated items.

(iii) Install rigid electrical conduit connections when flexible couplings should be used. It is important to note that the flexible couplings must occur between the points where the conduit or pipe is connected to the machine and to the fixed structure.

(iv) Install rigid fluid pipe lines. Flexible connections are manufactured for this purpose but care must be taken in their selection as some bellows, theoretically called flexible, expand and become rigid under operational pressure. From a practical point of view the best solution to this problem is to mount the machine on anti-vibration mountings and ensure that for a distance equivalent to 50 to 100 times the diameter of the pipework only flexible hangers or supports are used to carry the pipework. The pipework must also be sleeved using resilient material where it passes through any structure. Many of these bridges are due to ignorance or carelessness and some require considerable thought and expense to cure after the event.

1.3 (v) <u>Plumbing</u>

Much of the foregoing is also applicable to water systems. Pumps and other moving equipment should be sited on anti-vibration mountings and pipework associated with them suspended on resilient hangers. Pipework passing through structures must be carefully designed with resilient sections or sleeves where necessary. All holes for services must be completely sealed after the services have been installed as described in 1.3 (iv)c (iv).

One of the most common routes for sound leakage between adjacent areas is at the skirting level when pipework passes from area to area. This must be infilled with pugging bags filled with dry sand or heavy density mineral wool after the pipes have been installed.

Rain water pipes or other pipes associated with plumbing systems should not be taken through studios or technical areas without the approval of the acoustics consultant. Should it be agreed that pipework can pass through an area then the pipes must be encased in a solid structure and the cavity around the pipe packed with mineral wool to provide absorption of any noise.

NO sanitary fitting may be fixed to any structure enclosing a studio or technical area. This particularly applies to toilet cisterns, towel roll holders and hand dryers.

1.3(vi) Lifts

Where possible, lifts and lift machinery should always be sited well away from noise-sensitive areas. Where this is not possible, the following precautions should be observed.

The lift winding gear or hydraulic pump should be placed on anti-vibration mountings of large static deflection (at least 25mm) in order to minimise structure-borne vibration.

A hydraulic system should have a silencer installed at the pump outlet to reduce the vibration generated by the lift ram. The silencer should itself be supported on high-deflection anti-vibration mounts, or share those of the pump.

Prior to equipment installation, all inner surfaces of the lift shaft should be emulsion painted to reduce dust. This helps prevent wear and eventual noise from lift guides and ram seals.

Ram seals should be maintained in good condition and guide rails should be accurately aligned and properly lubricated.

Lift doors should also be regularly maintained to avoid excessive structural vibration and airborne nose.
It should be noted that it is not possible effectively to isolate a heavy pump supported on a lightweight floor. It is generally advisable to mount the lift pumps at ground level.

1.4 Environmental Noise

Local authorities have become increasingly aware over the past few years of the effect of noise on neighbours and of noise pollution in general. They normally impose a limit for the maximum noise level at the boundary of any new development which varies according to the occupancy and use of the adjoining properties. However in cases where the adjoining buildings are used for domestic or similar purposes, noise level limits imposed by local authorities have been known to be as stringent as NR 30 or 35.

These noise level restrictions are particularly important when considering continuous noise generated by ventilation plant, cooling towers, chillers and from other machinery such as diesel generators. Care should be taken to avoid siting such noisy equipment too close to the boundary otherwise expensive screening structures and/or attenuation will be necessary.

1.5 Modular Studios

The operational acoustic requirements for any studio, control cubicle or technical area constructed in modular form are the same as those required for an equivalent area built in traditional building materials.

The same standards for background noise should be applied equally to both forms of construction and the relevant BBC noise criterion curve (i), (ii) and (iii) (see figure 1) should be specified for any modular studio or technical area.

1.6 Outside Broadcast Vehicles

Achieving low noise levels within an outside broadcast vehicle when the compressors and air handling units are sited so close to the rooms they serve is an art form in its own right. Over the years the BBC Research Department have, in conjunction with the users, established a noise criterion of 10 dB above Criterion (i) (see figure 1) for new sound only vehicles and 15 dB above criterion (i) for new Television vehicles. However achieving these curves relies on careful planning, attenuation and overall attention to detail.

As in conventional studios and control rooms, noise in an Outside Broadcast vehicle may be caused by local sources within the vehicle or by external noise transmitted through the enclosing surfaces. The ventilation system is probably the most important source of locally generated noise, and conventional procedures may be applied to control it. Ducts and ports are smaller than in conventional areas and air velocities correspondingly higher, leading to increased turbulence. Ducts can be lined with absorbent material to attenuate ductborne sound but the duct lengths may be rather short for this technique to be fully effective. It is necessary for both the inlet and outlet ducts to be at least 2 metres long and internally lined with 18mm thick foam or similar absorbent material. This length of ducting is often difficult to provide within the confines of a vehicle. One successful solution is to site the air handling unit over the top of the cab. The inlet duct can then be run along the ceiling towards the rear of the vehicle and the extract duct formed within a false wall behind the cab. Ductwork should be constructed from 25mm thick blockboard, plywood, or similar density material to avoid sound break-out via the duct walls.

Full air-conditioning is usually provided in larger vehicles and noise from the conditioning plant needs to be controlled.

A critical factor in the selection of the air-conditioning plant is the accurate prediction of heat loads within the vehicle as larger units generate more noise.

Variable airspeeds can be a useful aid in controlling the noise, with the normal setting adjusted as low as possible for the specified heat load and the high setting only used in extreme conditions.

Normally a 10% fresh/recirculated air ratio is used for the supply system with the vehicle interior at a higher pressure than the exterior. A small vent into the plenum fitted with baffles or lined ductwork is used for the supply system. Stale air is extracted through ducting in the vehicle floor with a small extract fan/heater working in reverse or a small section of lined ductwork being provided. All door seals must be airtight to avoid 'hissing'.

Usually the main noise problem from vehicle air-conditioning systems is due to the low-frequency noise generated by the refrigeration compressor. The compressor is normally separated from the cooling units and sited outside the sound insulating structure of the vehicle. The precise position of suspension under the vehicle is determined by the weight distribution of the vehicle. Any connections between the compressor and the cooler must be via plastic pipes with the compressor itself being mounted on anti-vibration mountings and the framework supporting the compressor/condenser being isolated from the vehicle by further anti-vibration mounts. Any gas bypass valves must be selected to minimise "hiss" and "clonks" during operation.

On the basis that continuous noise is less disturbing than intermittent noise, the compressor should run continuously and temperature control be provided by auxiliary heaters in the air flow.

The problem of noise from technical equipment is exacerbated by the small size of the vehicle, because such items will be closer to the operator than in a conventional room. It is sometimes possible to place equipment requiring limited access within a ventilated cupboard fitted with glass doors to allow observation of indicator lamps etc. This provides a useful degree of sound reduction. In other cases equipment may be placed in a separate compartment in the vehicle.

1.7 Noise from Technical Equipment

Specifications for broadcast studios and technical areas normally include a criterion for the maximum permissible background noise level. Traditionally, these criteria have been directed towards the designers and manufacturers of ventilation plant in order that the noise from such plant should be kept down to an acceptable level. They also dictate the degree of sound insulation needed to avoid intrusion of extraneous noise from adjacent areas. It is, however, important to recognise that the criteria relate to noise from any source and this includes the technical plant installed within the areas concerned.

Component packing densities in modern equipment can give rise to heat problems

which are often overcome by the use of cooling fans. This now occurs so often that in some technical areas, noise from cooling fans has reached a level which is intolerable to the staff working there, even where critical sound monitoring is not involved. Another example is buzzing effects from TV monitors in metal framed stacks. It is therefore essential that every effort is made in the design of technical equipment to ensure that the equipment does not generate excessive acoustic noise.

Ideally, any noisy item should be sited in a separate apparatus room, or placed in an acoustically designed enclosure (see section 4.1). However, if this is not possible, it will be necessary to direct attention towards reducing the noise as much as possible.

Different approaches to equipment design could significantly affect the problem of heat dissipation. For instance, vertically mounted component boards on a vertical mother board are considerably easier to cool by natural convection than a unit with all boards mounted horizontally on top of one another. In addition, large slow moving fans are significantly quieter than small fast fans. It is to be hoped that, by prior knowledge of the acoustic noise requirements which the BBC specifies for technical equipment destined for occupied rooms, manufacturers will be encouraged to reduce fan noise or even eliminate fans from their equipment designs.

The level of noise which can be tolerated depends on the background noise criterion for the room in which the equipment is to be installed. Because of the additive effect of several noise sources, the noise from individual items of equipment should not exceed 5dB below the relevant criterion. For example, it is now recommended that the background noise level in manned apparatus rooms without monitoring facilities should not exceed NR45, so the noise generated by any item of equipment to be installed in such rooms should be below NR40. The background noise criterion for a BBC television sound control room or radio studio cubicle would usually be specified as Criterion (ii). Therefore Criterion (iii) is the level specified for technical equipment noise. The criteria referred to above are shown in figures 1, 2 and 3.
BBC specifications for broadcasting equipment will normally include a clause stating the acoustic noise criterion to be met and if necessary, specialist advice may be sought on methods of measurement when equipment is offered for acceptance. Similarly, when purchasing standard commercial equipment, the BBC will take account of acoustic noise performance as part of the assessment process.

Teleprinters produce noise and should be sited outside critical areas. When sited in News Rooms or similar areas they should be provided with proprietary acoustic hoods or be enclosed in builder's work shelving with all available surfaces around the machine covered in acoustically absorbent material.

The directly radiated sound energy may be reduced by absorbent screens placed between the teleprinters and the room occupants or alternatively the acoustic enclosure around the machines formed as an alcove with sliding glazed doors or windows.

1.8 Noise from Electrical Services

Electrical equipment which generates noise should, wherever possible be located outside the critical area. The main items to be considered under this heading are:-

(i) Fluorescent lighting fittings

The choke is the main source of noise emanating from the fitting but, in practice, the problem is associated with amplification by the construction of the lighting unit in which it is fitted because of the relatively large area of metalwork and other components free to vibrate with the choke. Further amplification may be associated with the environment (e.g. the type of ceiling to which the fittings are fixed or suspended). The fundamental 100 Hz noise is less troublesome than harmonics at higher frequencies.

It follows, therefore that the chokes must be located outside the critical area in suitably ventilated boxes or cupboards not fixed to structural walls or partitions directly associated with any critical area.

Fluorescent lights with high frequency control equipment usually have considerably lower noise than those with traditional choke ballasts, and can be useful in some studio

applications. However it is a mistake to believe that they are completely silent, as they incorporate mains filters which can produce a slight buzz. There are significant differences between different makes of control equipment in this respect, and there may also be sample variations between individual units. It is therefore recommended that in more critical areas, remote chokes should continue to be used. This recommendation is subject to a continuing test programme, and it may be that in future, high frequency fittings will be more generally used in studios.

(ii) Lighting fittings - general

Louvres, diffusers and other lighting accessories are often of a flimsy construction which can vibrate when subjected to music or speech in Radio or Television areas. Light fittings sited near the head of a broadcaster or other sound source are a particular hazard in this respect. Care must therefore be exercised in the selection of fittings and steps taken to mitigate these factors with such treatment as damping with suitable damping compounds. In general, a recessed 600mm square fitting with a flat diffuser, supported at the edges with rubber strips to prevent rattles, is far more acceptable acoustically than the lightweight criss-cross open diffuser.

The choice of light fittings for Drama Studios is extremely critical.

Hollow tubes, functional or decorative, should be sealed off to avoid "organ-pipe" effects.

Transformers used for battery charging of emergency lighting or for low voltage lighting and dimmers can cause an electrical hum which is particularly noticeable in small rooms. Therefore the type of system or fittings used in studio or technical areas should be carefully selected and any potentially noisy items installed in a separate location away from noise sensitive rooms so that this problem does not occur.

Dimmer controlled lamps can produce an unacceptable noise and consequently are not recommended for use in radio studios.

(iii) Electrical Floor Trunking

The recessing of electrical trunking with floor sockets into a structural floor can cause noise from footsteps or other impact sources to be transmitted into the structure via the ductwork and then into rooms below the floor. Consequently this system must not be used over studio or other critical areas.

(iv) Relays and Contactors

Continuous acoustic noise from the traction coil can usually be eliminated by the use of a DC coil. Nevertheless, noise associated with the operation of the relay or contactors will not usually be acceptable. Careful consideration must therefore be given to locations remote from the critical areas.

(v) Studio Clocks

Mechanical studio clocks other than oil-damped ones can often become noise generators especially when they are mounted directly onto a lightweight partition or backing which can vibrate. The noise they produce is particularly noticeable in the quiet environment of a studio.

The BBC Research Department has conducted an investigation into the problems of noisy studio clocks and found, from the clocks examined, that the commonest cause of the noise was the failure to remove the transit clamps on the anti-vibration mountings. In addition, the investigation showed that an increase in noise could be expected if the normal working current differed from the recommended one. Therefore it is important that these two points be checked when a clock is installed.

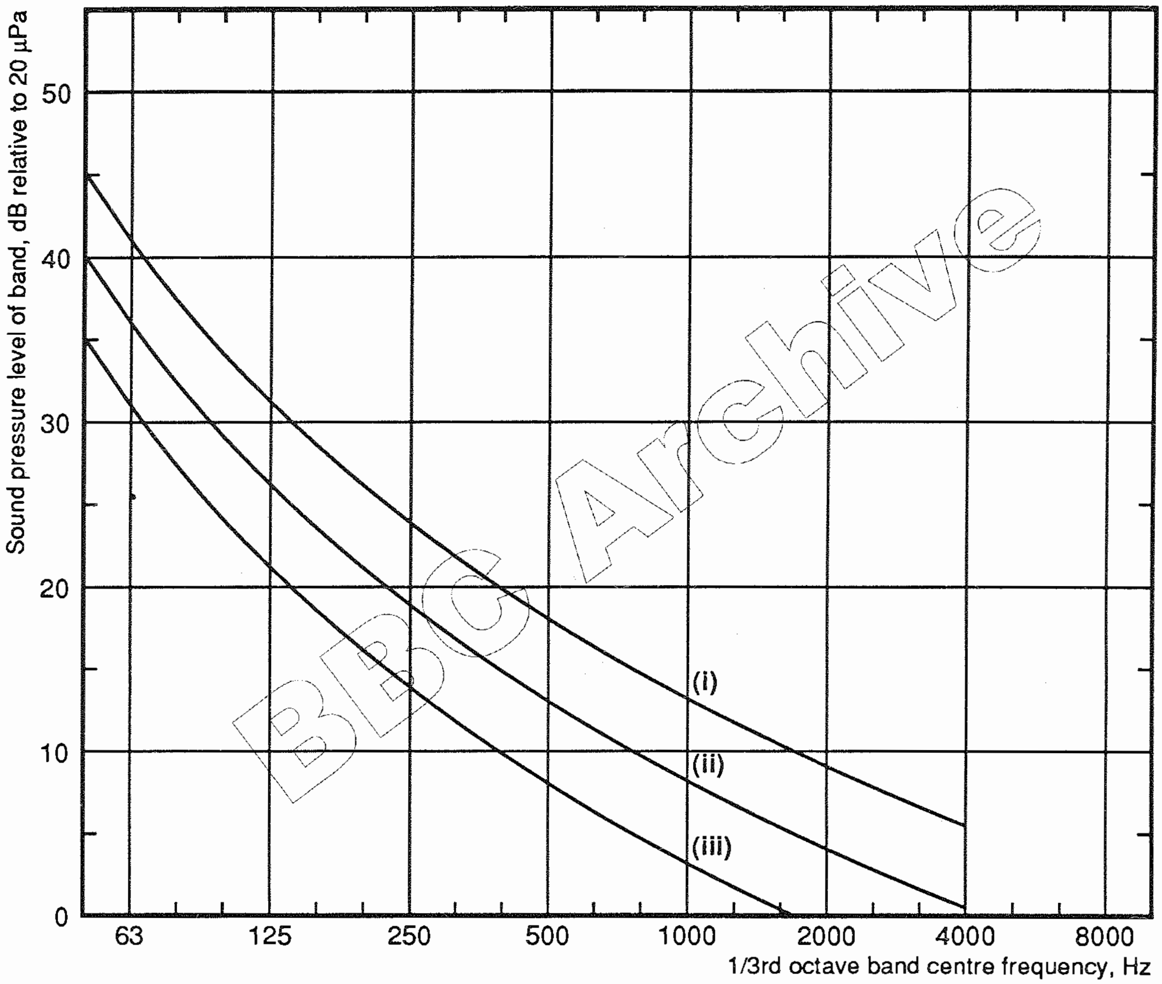
(vi) Stand-by Diesel Generators

Stand-by diesel generators are provided in the majority of BBC studio and transmitter premises. The diesel generator itself must be sited in a separate room as far away as possible from noise sensitive areas and installed on an effective anti-vibration system. Sufficient airborne insulation should be provided around the diesel to reduce the noise level outside the diesel chamber to an acceptable level and all air intakes and extracts and exhausts should be fitted with attenuators if the noise is likely to be a problem to neighbouring buildings, or nearby studios.

It should also be noted that the diesel must not be sited in any ventilation plant room

serving studio areas as the noise from the diesel will be transmitted into the studios via the air-conditioning ductwork.

Any pipework or cable connected to the diesel must have flexible lengths in it to avoid transmission of sound energy into the building structure, but note should be taken of the precautions referred to in sub-sections 1.3(iv)(c).



One-third octave band background noise criteria
For ventilation noise only

Criterion (i) Radio Light Entertainment studios.
(ii) All radio studios other than category (i) or (iii) and all Control Cubicles. All Television areas. Ancillary areas in radio and television, for example Listening Rooms.
(iii) Radio Drama studios only.

Figure 1 BBC Noise Criteria for maximum tolerable background noise in studios from ventilation systems

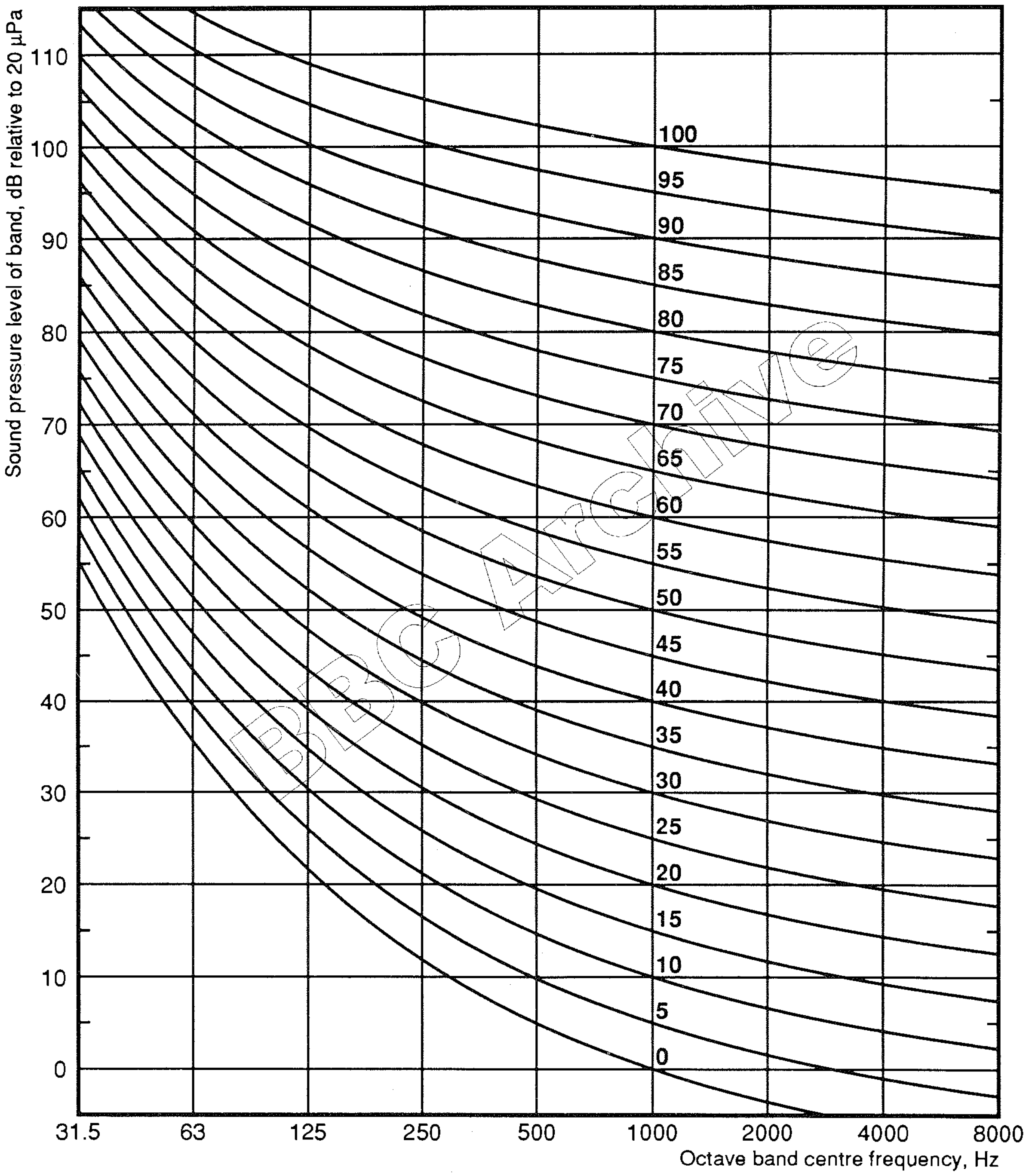


Figure 2 Noise Rating Curves. Octave Analysis

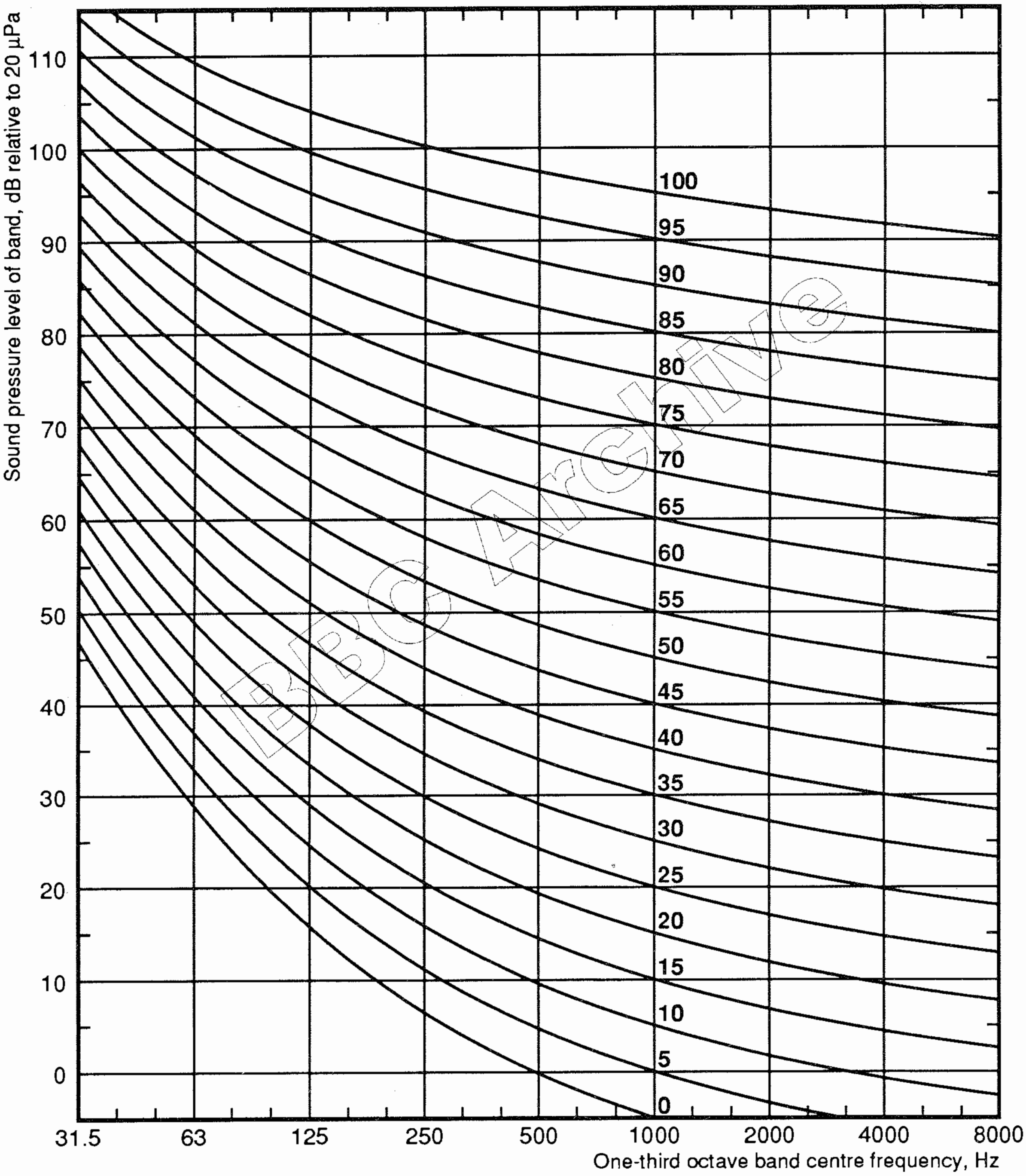


Figure 3 Noise Rating Curves. One-third Octave Analysis

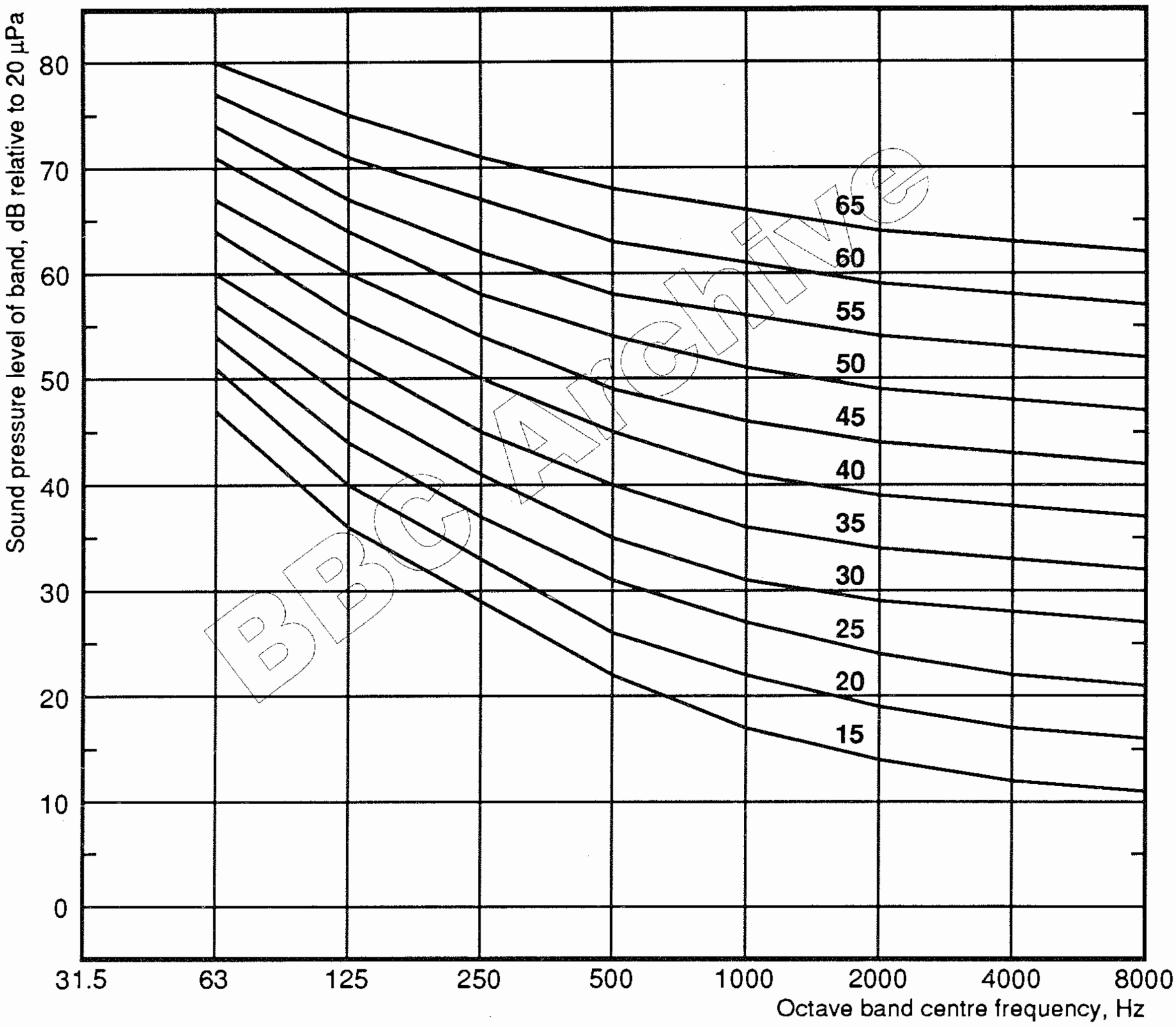
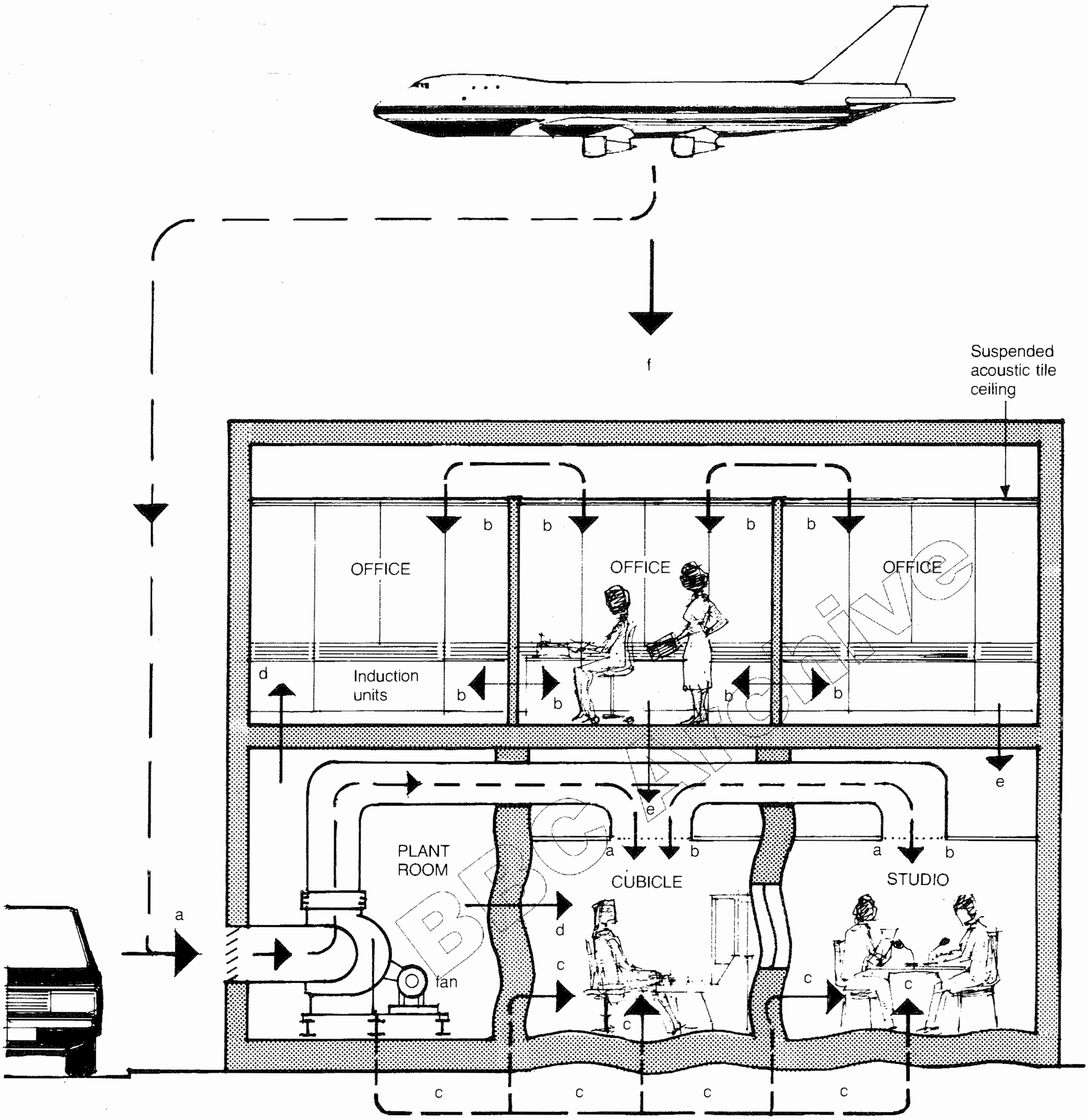


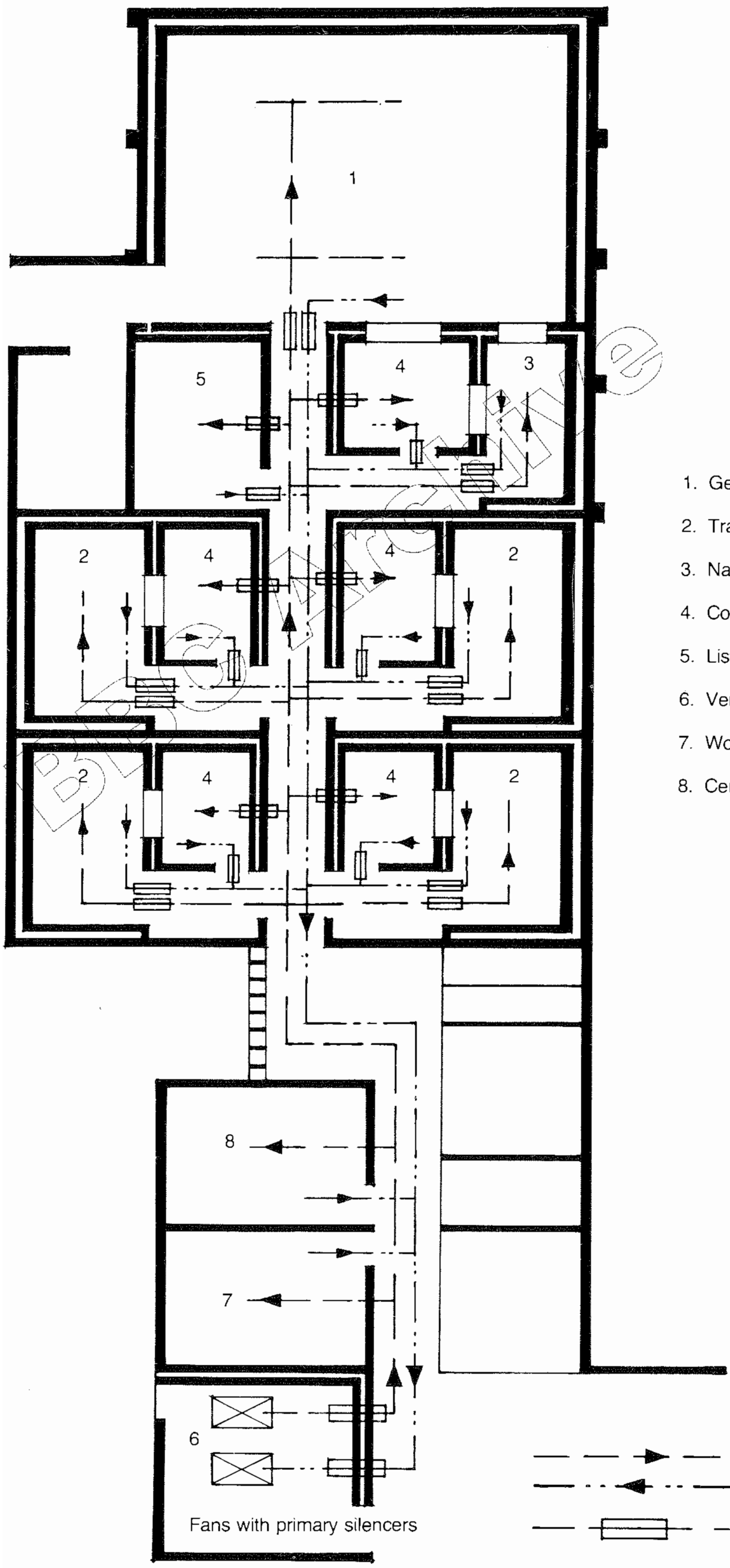
Figure 4 Noise Criteria Curves. Octave Analysis



SECTION THROUGH TYPICAL BUILDING

a. Noise transmitted into rooms from sources external to the building via the ventilation system.
b. Noise transmitted through or along ducts, or through ceiling voids, from internal sources ie ventilation plant noise or noises from adjacent rooms.
c. Machine vibration transmitted via the building structure.
d. Airborne noise breakthrough from the ventilation plant.
e. Impact noise from office areas to technical areas.
f. Airborne noise from sources external to the building entering rooms via the building structure.

Figure 5 Noise Transmission Paths



1. General Purpose Studio
2. Transmission Studio
3. Narrator's Studio
4. Control Cubicle
5. Listening Room
6. Ventilation Plant Room
7. Workshop
8. Central Apparatus Room

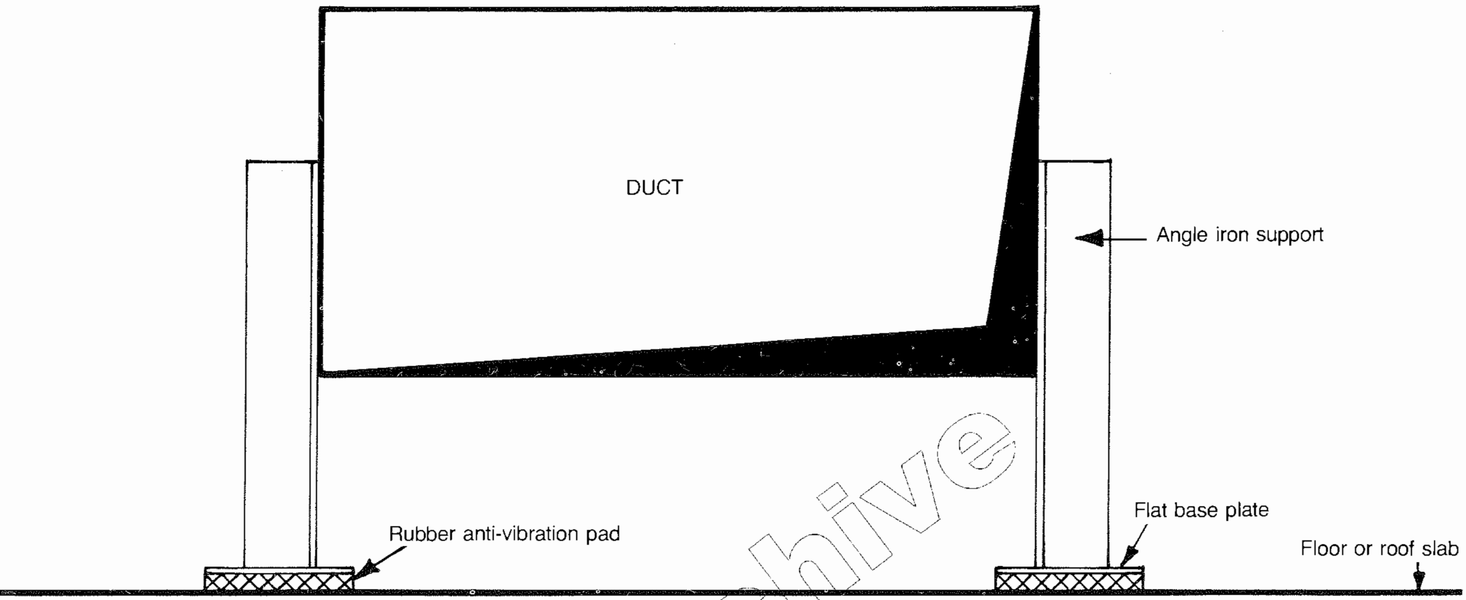
Supply system

Extract system

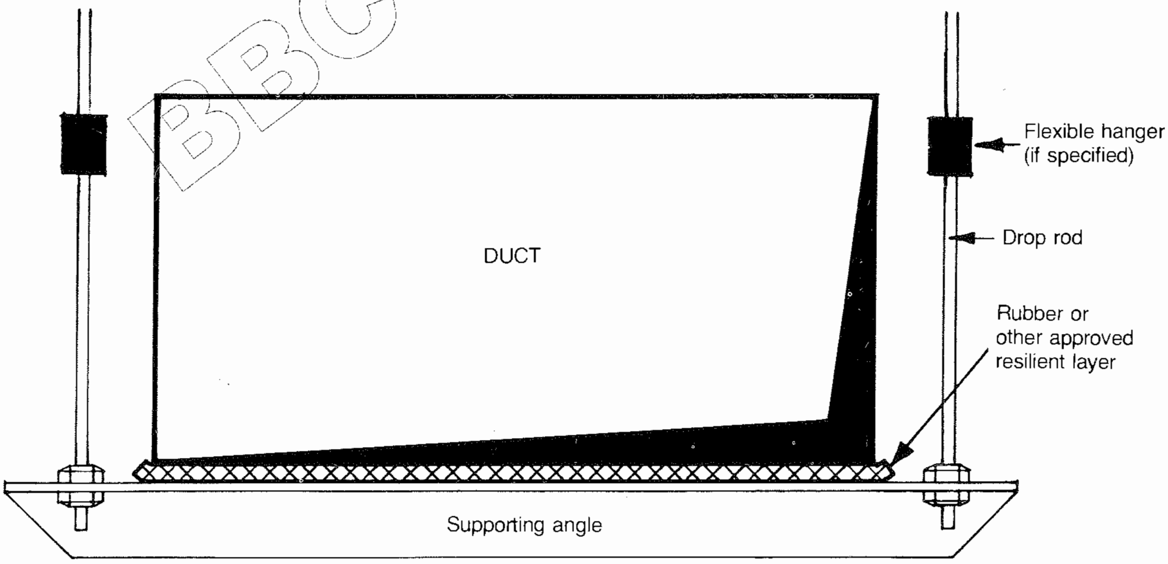
Cross-talk attenuators selected to match the weakest element in the wall. (see 1.3 (iv) b (iii))

Figure 6 Plan showing positioning of cross-talk attenuators in a typical studio ventilation system

NOTE: Any pipework or conduit supported
from ductwork or off ductwork supports
must be resiliently mounted.



SECTION SHOWING METHOD OF ISOLATING SHEET METAL DUCTS WHEN SUPPORTED OFF FLOOR OR ROOF SLAB



SECTION SHOWING METHOD OF ISOLATING SHEET METAL DUCTS WHEN SUPPORTED FROM ABOVE

Figure 7 Typical details for supporting ventilation ductwork

SECTION 2 SOUND INSULATION

ILLUSTRATIONS

PHOTOGRAPHS

2.1 Introduction (Figure 8, 9, 10 and 11)

Airborne sound insulation, sound absorption, and thermal insulation are often confused by the use of the loose terminology "insulation" or "absorption" and mistakenly thought to have similar properties and solutions whereas in actual fact their requirements are generally very different.

Airborne sound insulation requires mass, discontinuity or resilience to achieve its aim of stopping sound energy being transmitted from one area to another via the building structure; in contrast sound absorption relies on the provision of materials within an enclosed space that will absorb the sound energy over a wide range of frequencies. The most efficient materials for this purpose are generally lightweight and applied direct to the internal surfaces of a room.

Thermal insulation requires sealed cavities or composite structures to retain heat energy using lightweight materials such as mineral wool, glass fibre or polystyrene, often sandwiched into the structure or wrapped around various elements to provide the necessary thermal insulation values.

Mineral wool and glass fibre can also provide sound absorption but any improvement gained to the overall sound insulation between rooms by their use is provided solely by the reduction in the reverberant sound energy by the absorbent materials within a room.

It is a common fallacy that acoustically absorbing materials will dramatically improve the sound insulation value of a structure. If one remembers that to achieve a significant increase in the sound insulation value of a structure it is necessary to double its mass (see figure 8 and the list of the comparison of weights of building materials in figure 9), it can be seen that applying acoustic tiles or similar lightweight sound absorbing materials directly onto the surface of say a 225mm thick brick wall will not have any appreciable effect on its overall sound insulation value.

The most common confusion between sound insulation and thermal insulation occurs when the term "insulation" is used in reference to double glazing. For thermal insulation a narrow sealed cavity is all that is required, whereas for sound insulation purposes a cavity of a few millimetres is insignificant. The only benefit gained to the sound insulation value of the double glazing is from the additional weight of the extra pane of glass. This serves to double the original mass and generally provides an average improvement of approximately 5 dB to the sound insulation over the frequency range 100 Hz to 2.5 kHz. However if the cavity between the panes were to be increased to 150mm or 250mm and absorption provided to the cavity reveals, the average improvement to the sound insulation would be of the order of 17 dB over the same frequency range.

Sound insulation itself is sub-divided into two separate categories, each of which calls for differing solutions. This is because sound energy can be transmitted from one area to another by either airborne or structure borne paths.

The solution to airborne sound insulation is generally to provide mass controlled barriers between the areas, of single, double or even triple cavity construction, whereas the problem of structure borne transmission is usually solved by the introduction of resilience or discontinuity at either the source or receiving area, or in some instances, both.

It is therefore important to examine all aspects of an "insulation" problem before specifying a solution.

In order to pass through an impervious structure sound energy must move the structure to and fro. The average airborne sound insulation value of a single-leaf structure is therefore almost entirely determined by its mass per unit area. This is known as the 'Mass Law' principle, the curve for which is plotted in figure 8 together with a list of weights for typical building materials in figure 9.

For a single-leaf structure the airborne sound insulation increases by about 5 dB for every doubling of the frequency (i.e. per octave). For a complete description of the structure, its insulation values over the whole frequency range should be given. However, for convenience a single figure is often obtained by taking the average of the airborne insulation values over the frequency range 100 Hz to 2.5 kHz.

Where a high degree of airborne sound insulation is required, i.e. greater than 50 dB it is normal practice to specify double or triple leaf constructions which have substantial airspaces between the leaves. Under such circumstances, a double leaf structure would have a sound insulation characteristic which increases by about 10 dB for every doubling of the frequency, compared with 5 dB for a single leaf structure, and the sound insulation value of a triple leaf construction would increase by approximately 15 dB for every doubling of the frequency.

2.1 (a) Criteria

After extensive studies and discussions, the BBC has produced a set of standardized sound insulation criteria covering most of the types of areas found in broadcasting premises. These take into account normal interference sources and the sensitivity of areas to disturbance from outside. The table shown in figure 10 illustrates the normal criteria in the form of a chart giving minimum airborne sound pressure level differences as a function of frequency for approximately 400 area pair combinations.

Figure 11 illustrates four worked examples of the criteria.

The general shape of the characteristics shown in Figure 11, that is low values of sound insulation at low frequencies rising to a maximum level at an intermediate frequency (around 500 Hz - 1 kHz) and remaining at this level or falling slightly at frequencies above 1 kHz - 2 kHz, is typical of all of the requirements and derives mainly from the shape of the background noise level criteria. The small deviations from this regular shape are due to the deviations from a uniform sound pressure level in the source area.

Fortunately, there is a feature of all partitions which, at least in theory, can be used to reduce each sound insulation requirement to a series of consecutive straight lines.

Theoretically, an infinite, limp partition has a sound reduction index which increases by 6 dB for every doubling of the measurement frequency and by 6dB for every doubling of its superficial mass. Two such partitions, sufficiently far apart to be independent of each other, have a characteristic slope of 12 dB/octave. In practice, as a result of the partition being finite and stiff, the average slope of a single partition is approximately 5 dB/octave. A double partition with a small spacing between the leaves, such as a conventional cavity wall, has leaves which are not far enough apart to be independent and has an average characteristic slope of about 8 dB/octave. These figures actually only apply above the frequency at which the wall mass resonates with the stiffness, i.e. where the characteristic is mass-controlled. For walls of normal construction as used for sound insulation purposes, this resonant frequency is quite low.

For the purposes of sound insulation, the partitions can be divided into four categories:-

(1) Single leaf walls: 5 dB/octave

(2) Double leaf construction with a small cavity 50 - 300mm: 8 dB/octave

(3) Double leaf construction with a large cavity 300mm upwards: 10 dB/octave

(4) Triple leaf construction: 15 dB/octave.

It must be remembered that these are only approximations and individual partitions may deviate from them, especially at low frequencies. Nevertheless, these categories provide a means by which any required sound insulation characteristic can be reduced to a simple series of numbers.

The sound insulation requirements derived for all meaningful combinations of areas were converted to sound insulation criteria by the BBC Research Department and the resulting sets of numbers were entered into the appropriate spaces in the chart shown in Figure 10. At each intersection of a row and a column in Figure 10 the six numbers within the rectangle represent the value of the sound pressure level difference criterion at 63 Hz, and at the four intersections of the lines with slopes of 15, 10, 8, 5 and 0 dB/octave. The numbers are taken from left to right and from top to bottom, beginning with the top left number. The bottom right number is the approximate frequency in hundreds of hertz at which the intersection of the 5 dB/octave and the 0 dB/octave lines occurs. It is included as a check that the criterion has been correctly reconstructed.

Some possible entries in Figure 10 are not valid and are indicated by X. This means that there is no requirement for sound insulation in those cases.

The values given by the chart represent the insulation necessary to ensure complete freedom from disturbing interferences. In many cases, 5dB less can be tolerated giving a more economic compromise, at the cost of some occasional significant disruption.

2.1 (b) Tolerances

The tolerances which are to be applied to the sound insulation criteria reflect the different sensitivities of the types of rooms. Programme areas have more stringent tolerance limits than non-programme areas.

'Programme Areas'

There is no acoustic penalty in values of sound insulation which exceed the criterion. Accordingly, all tolerances are specified in terms of adverse deviation which is defined as the criterion minus the achieved sound insulation. It is set equal to zero if it would otherwise be negative.

In setting these tolerances it is recognised that there are difficulties in the design of partitions and the measurement of sound insulation at low frequencies. Accordingly, the tolerances have been divided into two frequency bands.

The permitted tolerances for areas in which programme making or critical assessment of sound quality are carried out (these include all areas covered by background noise criteria (i), (ii) and (iii), by criteria derived relative to them or other critical area criteria as specified) are as follows:

Low Frequencies

In the frequency range 63 Hz to 200 Hz the average of the adverse differences shall be less than 6 dB and no individual adverse difference shall exceed 10 dB.

High Frequencies

In the frequency range 250 Hz to 8 kHz the average of the adverse differences shall be less than 2 dB and no individual adverse difference shall exceed 5 dB.

'Non-programme Areas'

Non-critical areas have larger tolerances for sound insulation. However, this relaxation applies only if both of the areas fall outside the definition of critical area. In these cases the tolerance is that no adverse difference shall be greater than 10 dB.

2.1 (c) Extension of Frequency Range

Acoustic criteria are normally specified over a limited frequency range. These ranges include the most critical frequencies of the ear to noise as picked up by the microphone in a studio. Outside these frequency ranges other factors, such as operator comfort, will normally impose a more severe limit than the subjective appraisal of the broadcast sound. However the acoustic criteria can be extended to cover the requirements of broadcast sound quality.

In the case of sound insulation very little data is available on which to base a specification but a considered opinion can be proposed. At frequencies above 8kHz there is normally little difficulty in obtaining sound insulation, whilst on the other hand most sound sources have a spectral content which falls with frequency and thus there may be little need for sound insulation.

For the sake of completeness however, it is specified that the sound insulation criterion above 8kHz shall be the same as the 8kHz criterion value. At low frequencies, i.e. below 63Hz, the situation is both more difficult and more likely to be critical. Not only is there a need to ensure extraneous noise does not become audible on the broadcast, but also, if the partition being specified is that between a studio and its control room, then there is a need to prevent acoustic feedback (howlround). It is therefore specified that below 63Hz the insulation criterion shall be allowed to fall by 15dB per octave to a minimum value of 20dB, unless the specified level at 63Hz is less than 20dB, in which case this value shall be regarded as the minimum value.

2.1(i) Practical Constructional Details

It should always be remembered that the predicted performance is totally dependent on a structure being built precisely to detail with no acoustic weaknesses. For example a crack only 300mm long x 6mm wide can reduce the effectiveness of a partition from 45 dB to 38 dB at high frequencies.

Timber frames around structural openings must always be bedded throughout in mastic where it butts up to brick, block or concrete reveals. This is an important point which has often been omitted in the past and only comes to light when complaints are received of poor insulation at high frequencies. On inspection it has been found that the usual cause is that the timber has shrunk and pulled away from the structure leaving a gap or that only a thin layer or bead of mastic has been applied after the building work has been completed and that this has subsequently shrunk and opened up a crack.

It is essential that timber is completely bedded in mastic or similar sealing compound as it is installed so that the possibility of problems caused by skrinkage are overcome by the introduction of an elastic material. Mastics or sealants, based on polysulphide liquid polymer are highly elastic when cured and are capable of accepting repeated expansion or contraction without cracking or loss of adhesion and consequently are ideal for use in these situations.

The use of high density mineral wool for filling holes is not recommended. Where it must be used it must be rammed tightly into the hole and a layer of plaster, cement or mastic applied to the exposed faces. This technique must only be used for small holes or gaps of not more than 6mm. Large holes must be made good throughout the thickness of a structure with solid material taking care not to bridge any intentional cavity. Where a hole is provided for cable or service runs the hole or duct must be pugged with bags filled with either dry sand or heavy density mineral wool.

REMEMBER SOUND WILL FIND ITS WAY THROUGH THE SLIGHTEST HOLE.

Where conduits or ducts pass through a wall or a floor, the gap around the conduit or duct must be properly sealed with cement mortar or material of similar mass. Where they pass through a cavity in a floated 'box within a box' structure the conduit or duct must have a flexible section of conduit or duct in the cavity or pass through resilient sleeves in the wall or floor, again to avoid bridging.

Structural expansion joints should normally be designed to pass outside a studio structure. However in certain situations they can be used to advantage in reducing structure borne noise between different parts of a building.

In providing runs for services the architect can create paths through which noise can travel from room to room: Examples of this are induction units or other perimeter air-handling devices, skirting trunkings or cable ducts which pass through a structure. These units or ducts are generally formed from sheet steel and are often of a generous size. It is essential that they are considered carefully and treated or filled, after the cables or pipes have been installed, with a material of substantial mass, usually in the form of sand pugging, at the point where they pass through the structure, otherwise all the time and money spent on elaborate acoustic construction will be wasted. Another example of sound breakthrough often occurs when walls or partitions finish against an external window mullion. Here the detailing is sometimes difficult as the wall is usually wider than the mullion; however, in the majority of situations the problem can be overcome by the provision of a triangular casing infilled with a slightly moistened mixture of sand and cement.

Preformed external wall cladding which incorporates services or service ducts in its thickness can also provide a route for noise transfer from one area to another when the cladding panels are fixed to the external face of the columns.

Current trends towards providing the client with the maximum flexibility for office layouts require that offices are often formed with demountable partitioning which, to minimise cost, is only erected up to the underside of a suspended ceiling. The void above the ceiling is no doubt excellent for services but it is disastrous acoustically. The void allows a clear route for sound to pass from office to office, making it

impossible on occasions to hold a conversation or interview without being overheard. Where offices are used for matters of a private or personal nature it is essential that they are enclosed with full height, slab to slab, partitioning and that any communicating door to an adjacent office is of a substantial nature with good acoustic seals. This also applies to offices where loudspeakers are used to monitor programme material. Occasionally, using a solid backed plaster acoustic ceiling tile may improve the situation if a lesser sound insulation standard is acceptable and a continuous void is required for services. A similar result may also be achieved by laying plasterboard or hardboard squares above the acoustic tiles or suspended ceiling, such potential improvements are however likely to be rendered ineffective if the ceiling is perforated by substantial areas of light fittings.

Inter office privacy can be reduced when induction units or other perimeter air-handling devices are installed. It is essential that partitions requiring good sound insulation are terminated at columns to ensure there is no breakthrough via the units.

Other routes for sound transmission of which the designer must be aware are vertical builder's, electrical or ventilation ductwork with thin walls or doors, passing from area to area. To improve the insulation through these ducts they must be either fitted with attenuators or filled with sand or mineral wool pugging as appropriate which must completely fill the hole in the structure. To pug a hole or duct the basic object is to fill the majority of the hole or duct with bags filled, or partially filled, with dry sand and then to ram in smaller bags, filled with high-density mineral wool, which will mould themselves around the cables and corners and seal the hole or duct.

For further explanation the topic of Sound Insulation has been sub-divided into the following building elements.

2.2 Framed Structures
2.3 Walls
2.4 Floors
2.5 Roofs and Ceilings
2.6 Staircases and Ramps
2.7 Studio Doors
2.8 Windows
2.9 Modular Studios
2.10 Outside Broadcast Vehicles
2.11 Mechanical Services
2.12 Technical Services
2.13 Electrical Services

2.2 Framed Structures

Framed structures are generally constructed in either steel or concrete with walls and floors provided either as integral parts of a structure or as infill panels. In the case of steel framed buildings it must always be borne in mind that steel readily transmits sound energy and should therefore be treated with caution when used in the design and construction of building for broadcasting.

Hollow casings around steel stanchions or beams must be avoided where steelwork forms any part of a structure enclosing a studio or technical area. It is essential that the steel be encased in a material of similar mass to that of the adjacent structure particularly where a stanchion or beam passes from one area to another. Unless the steel is solidly encased at the point where it passes through the structure, the hollow casing will provide a flanking path for airborne sound transmission.

Walls butting up to any framing should be connected as solidly as is possible (see section 2.3(i) Para. 4) and where a double wall is used, a staggered or rebated detail for the framing should be specified to eliminate the possibility of a direct sound path through the wall should the joints open up at a later date.

2.3 Walls

Wall Constructions used in the design of studio buildings can be grouped together into two basic categories.

(i) Brickwork, Dense Block, Lightweight Blockwork or Mass Concrete.

(ii) Lightweight Stud Partitioning.

(i) Brickwork, Dense Block, Lightweight Blockwork or Mass Concrete (Figures 12 and 13)

These four forms of construction all rely primarily on mass to provide good sound

insulation and it is essential that they have no structural weakness whatsoever. All brick and block walls must be constructed with the bricks or blocks fully bedded in mortar throughout the wall with no gaps, cracks or voids in the wall. To ensure that this is the case it is essential that all walls are plastered or rendered to achieve the maximum sound insulation from the structure.

Where any wall is angled the bricks or blocks must be cut to shape to avoid bridging any cavities and all junctions and angles must be fully bedded in mortar.

Bricks used in the construction of studio walls should be as heavy as is possible with a minimum weight of 2.3 kg to 2.5 kg per brick being acceptable. Where bricks are used which have frogs, they must be bedded in mortar with the frogs uppermost to ensure that the wall is solid throughout and that the correct overall weight for the wall is achieved by the frogs being completely filled with mortar. Perforated bricks should not be used for studio construction.

The use of wall ties can significantly alter the acoustic performance of a wall. A double leaf wall, partially tied, will only provide a sound insulation slope of 5 dB for every doubling of the frequency compared with the 10 dB per octave slope previously mentioned and a similar reduction can be expected with a triple leaf construction. Therefore the use of wall ties should avoided wherever possible.

In some instances the use of wall ties is unavoidable, perhaps being required for structural reasons or by the local authority. Under these circumstances they should be kept to a minimum and a typical specification is to have special flexible ties staggered and uniformly spaced at 900mm centres horizontally and 450mm centres vertically. Additional ties should be provided at all openings, 150mm from the edge of the opening and every 225mm in height. Each tie should be embedded a minimum of 50mm in each leaf.

The acoustic benefits gained by using flexible wall ties as against standard wall ties are illustrated in figure 12.

Where a new wall butts up to an existing solid wall and a brick or block wall plating system is used to connect the walls to each other the wall plate must be bedded in mastic against the existing wall to ensure that there are no gaps around the end of the new wall. The new wall must be seated within the wall plate and bedded fully in mortar. It is also a sensible precaution to use a proprietary corner reinforcing mesh to avoid cracking in the plaster surface at the junction of the walls.

To avoid low frequency breakthrough between adjacent technical areas with channel reinforced, pre-screeded, woodwool slabs suspended over them, it is essential that at least one leaf of any wall separating the areas be taken up through the void to the underside of the structural slab above the woodwool layer. The top of the wall must be isolated from the structural slab.

If the wall, which is illustrated in figure 20, is not provided within the void, howlround will occur between loudspeakers and microphones in adjacent rooms.

Care must be taken to ensure that the wall carried up through the void is not connected rigidly to any adjacent, independently mounted wall which may abut the wall in question; otherwise acoustic bridging will occur.

Although bricks are preferable to any other material for the construction of studio walls, blockwork sometimes has to be used and in these cases dense solid concrete blocks are recommended which have a weight of approximately 2 tonne/ m^3. In some instances lightweight blockwork has to be used particularly in existing buildings where the structure is not strong enough to support a heavy wall. In this situation the selection of the blocks must be carefully considered as some manufacturers produce a product that is prone to ringing and consequently has poorer sound insulating properties than other blocks, particularly around 160 Hz to 500 Hz.

It should also be noted that lightweight blockwork generally has poorer sound insulation values at low frequencies than either brickwork or heavy blockwork. Block walls are basically porous by nature and must always be plastered or rendered to achieve satisfactory sound insulation.

Typical sound pressure level differences for brick and blockwork constructions are shown in Figures 12 and 13.

A single brick or block wall must be plastered on both faces and a double wall should be plastered at least on the outer two faces. In the case of a triple wall one face of the centre leaf must be plastered or rendered in addition to the outer faces of the two skins of brick or blockwork.

In situ concrete is one of the most predictable building materials provided that the concrete is properly compacted and vibrated to eliminate all voids. However, broadcasting studios tend to require a degree of structural adaptability as they are often refurbished and this sometimes necessitates enlarging areas, usually by the removal of walls. Concrete with its reinforcing bars or mesh reinforcement does not lend itself to this operation and consequently its use is generally avoided in the construction of studio walls.

In the construction of double or triple cavity walls 50mm non foil backed mineral wool slabs are generally used as a cavity infill or as a permanent shuttering to the cavity. Polystyrene or rigid polyurethane foam was originally used as the cavity infill but was discontinued in 1983 when the BBC Research Department found that using nearly-rigid materials to fill the space inside a cavity wall can have serious deleterious effects on the sound insulating properties of the wall.

Cavity infill materials less rigid than polystyrene or rigid polyurethane foam, such as mineral wool, may increase the low-frequency sound insulation of a cavity wall by increasing the effective cavity size and will increase the high frequency insulation by absorbing high frequency sound energy within the cavity.

The use of a cavity infill has the added advantage that the cavity can be kept completely clean of mortar droppings, which is absolutely essential particularly if 'box within a box' floated structures are being used. One lump of mortar bridging the cavity can transmit sound vibrations from one wall to the other and thereby ruin the elaborate precautions taken by the careful and intricate detailing of floating structures. Where mineral wool slabs are not used then the text book method of keeping the cavity clean with moveable battens within the cavity, which are raised as the wall height increases, should be strictly enforced. In the case of 'box within a box' structures low level inspection holes should be left at regular intervals in the outer leaf of the cavity wall so that the cavity can be regularly checked. At the completion of the building contract it is a sensible precaution to seal off the cavity at the top with a flexible sealing joint if the roof slab is accessible and the possibility exists of rubbish being dropped into the cavity.

Where doors to different areas are sited in the same cavity wall it is essential that the doors be fixed to the inner leaf of the wall or in such a position as to avoid the cavity becoming a route for sound passing from one area to another and becoming a flanking path.

Door or window linings in cavity walls should only be fixed to one leaf unless a flexible joint is provided along the centre line of the cavity.

In 'box within a box' structures care must be taken to ensure that there is no possibility of the floated structure being bridged by a structural element. No resiliently mounted wall should abut a structural frame but must be carried around that frame in the form of a casing with no connection whatsoever.

Expansion joints in framed structures must be designed to pass outside a studio area. However in certain situations they can be used to advantage in reducing structure borne noise between different parts of a building

(ii) Lightweight Stud Partitioning (Figures 14, 15 and 16)

Lightweight stud framed partitions have the same basic sound insulation problems as the previous types of constructions covered in this book and must also be constructed exactly to detail. They are only used in studio construction where the existing supporting structure will not permit the use of any other form of construction. Due to their lightness in weight, the sound insulation values of a single partition are not very high, particularly at low frequencies. As a result this type of partitioning is generally used as a double or triple construction.

The 'Camden' partition is used extensively in BBC Studios and other areas where a

lightweight stud framed partition is required. Originally designed for use in the Camden Theatre in the 1940's the partition consists of a layer of 12.5mm plasterboard, weighing approximately 11 kg/m^2, backed by a 12.5mm thick sheet of softboard fixed on either side of a 76mm x 50mm softwood stud framing. The vertical members of the framing are spaced at 0.6m centres and the horizontal ones at 1.2m centres with hairfelt carpet underfelt all round the edges where the Camden abuts another structure. Structural necessity often demands that the partition be tied to the adjacent structure but such fixings must be resilient.

The softboard which serves to damp the resonance in the plasterboard as well as partially isolating the plasterboard from the timber frame, contributes a significant proportion of the mass and therefore increases the sound insulating properties of the partition.

A single Camden provides approximately 35dB average sound pressure level difference over the frequency range 100 Hz to 2.5 kHz, a double Camden 52dB and a triple leaf Camden partition 87dB average all over the same frequency range. Their sound insulation characteristics are illustrated in Figure 16. The double or triple Camden partitions are generally considered to provide acceptable sound insulation for Talks, Discussion and Continuity Studios to their own Control Cubicles but are not suitable for Music or Drama studios where higher values of sound insulation are required at the low frequencies.

It is essential that there are no weaknesses acoustically and the softboard and plasterboard must be butt jointed only on timber members. All plasterboard joints must be properly sealed with taped joints and with a skim coat of plaster applied to the surface.

Where the second skin detail is used (see Figure 15) it is essential that the plasterboard and softboard on the inside leaf be cut accurately to form a tight fit within the studding, otherwise the sound insulation of the overall partition could be seriously degraded.

Also where double or triple partitions are used care must be taken to ensure that the leaves are not rigidly connected in any way, particularly at door or window openings and also where a double or triple Camden partition meets a single partition.

Where doors to different areas are sited adjacent to each other in a cavity wall it is essential that the doors be fixed to the inner leaf of the partition or in such a position as to avoid the cavity becoming a route for sound passing from one area to another thereby by-passing the doors.

Neither the door frame nor its linings must bridge any cavity or cavities between Camden partitions. The door frame must be rigidly fixed to one Camden with any linings isolated from the frame or provided with gaps where they span any cavity.

To make good a damaged area or a hole in a Camden partition, the plasterboard and softboard should be removed from around the damaged section so as to expose the horizontal and vertical timber framing. This will enable the replacement section to be fixed in the correct manner to the studding.

Timber framing butting up to new or existing walls, floors or ceilings should be sealed all round and fully bedded in mastic.

Where only a nominal improvement is required in the sound insulation of an existing structure, it is sometimes acceptable to add only a half partition which can be in the form of a double layer of 12.5mm plasterboard backed by 12.5mm softboard fixed onto a timber studding similar to that of the Camden partition. To have any appreciable effect on the overall insulation of, for example a domestic style party wall, the partition should be spaced at least 125mm away from the existing wall and must not be in contact with it in any way. A 25mm thick layer of mineral wool should be fixed in the cavity to provide acoustic absorption.

Where a woodwool slab ceiling is suspended over technical areas it is essential that the walls separating the areas be carried up through the void to the underside of the structural slab above. This is described in Section 2.3(i) para. 7.

Plaster and lath inner linings to external walls have been discovered in older properties and where they occur all new

partitions butting up to them must be taken through the plaster and lath lining and fixed directly onto the outer wall, thereby eliminating the flanking path around the partition via the cavity at the rear of the lining.

Another common flanking path for airborne sound transmission in properties of this age is through the space between the joists in the floor below or the ceiling above a partition supported off a timber structure. These spaces must be pugged along the line of the partition or alternatively, if the joists run the correct way, the partition should be erected on top of a joist.

Any hole in a lightweight partition must be sealed in a manner similar to that specified in the foregoing sections and any conduits or electrical ducts must be pugged on completion of the electrical installation.

Asbestos based sheets or boards must not be used in BBC premises. Asbestos based products can release fibres which constitute a serious health hazard for both the building contractors and the occupants of a building.

2.4 Floors

This section has been sub-divided into four parts.

(i) Solid Concrete Floors
(ii) Lightweight and Timber Floors
(iii) Floated Floors
(iv) Modular or Suspended Floors

(i) Solid Concrete Floors

Solid floors should be constructed with no structural weaknesses using correctly vibrated concrete.

Hollow casings around steel beams must be avoided where steelwork forms any part of a structure enclosing a studio or technical area. It is essential that steel beams are encased in concrete or material of similar mass particularly where they pass from one area to another. Unless beams are solidly encased at the point where they pass through the structure, the hollow casings will provide flanking paths for airborne sound transmission.
Television studio floors must be laid to a very precise specification to enable the television cameras to track across the studio without producing any visible variation in the picture. Any indentation in the floor surface will produce a movement of the picture as the camera passes over it. To obtain the required accuracy it has been found necessary in the past to lay an asphalt topping on the screed on top of the concrete sub-floor. The asphalt is laid in sections and is floated up to timber formwork fixed accurately in position, using surveying equipment to check the levels. The final finish to the studio floor is usually linoleum laid in sheet form. Hard-wearing, self levelling, epoxy resin floors on a concrete sub-structure have in some instances been laid as an alternative to the linoleum and asphalt floor.

In situations where a noisy area, such as a restaurant, is sited over a studio area it is advisable to incorporate a resilient layer of mineral wool between the reinforced floor screed and the structural slab to reduce impact noise. Care must be taken to ensure that no bridging occurs at the edges of the floated slab.

Ducts for electrical services, plug sockets etc. must not be set into solid floors over studio areas as the ducts and plug sockets will transmit impact sound energy from footsteps, tape trolleys or other sources direct into the structure and thence into the area below.

Generally holes through any floor should be avoided but where they are essential for services, the gap around the duct or pipework must be completely filled right through the floor. A surface layer of plaster or cement is not sufficient. For conduits, a cement-sand grout will penetrate around the pipes in a more satisfactory manner than a normal concrete mix.

The use of mineral wool infill alone for filling holes or gaps should be avoided but where it is used it must be rammed tightly into the hole or gap and a layer of plaster, cement or mastic applied to the outer faces. This technique must only be used for small holes or gaps of not more than 6mm. Where a larger hole is deliberately formed in the floor for cable runs, the hole must be pugged on completion of the electrical installation. To pug a hole or duct the basic object is to

fill the majority of the hole or duct with bags filled, or partially filled, with dry sand and then to ram in smaller bags, filled with high-density mineral wool, which will mould themselves around the cables and corners and seal the duct.

(ii) Lightweight and Timber Floors (Figure 17)

The use of lightweight and timber floors is to be avoided wherever possible, particularly in new buildings as, due to their lightness, they invariably have poor airborne sound insulation values, particularly at low frequencies. However in the conversion of older buildings into broadcasting centres the problem of existing lightweight floors often occurs and the question then arises of how to improve the insulation of the floor within the limitations set down by the load bearing capacity of the supporting structure. The ideal solution would be simply to increase the mass of the floor but in the case of a structure such as a hollow clay pot floor the only solution is generally to add a lightweight floating floor.

Improvement of timber domestic-type floors normally requires additional mass, usually in the form of dry sand pugging. To achieve this, battens are fixed to the sides of the joists, a layer of plywood or similar material is fixed above the battens and between the joists and then a minimum thickness of 25mm of dry sand is poured in place. A layer of polythene sheeting may be required under the sand to stop seepage into the area below.

A variation of the above method would be to place polythene sheeting on top of the existing floor, with minimum 25mm thick battens fixed above the polythene with a full depth layer of sand between the battens and new floor boarding finally being laid on top.

An alternative, and usually more effective, way of improving the airborne sound insulation through a lightweight floor is to suspend a false ceiling of pre-plastered, channel reinforced woodwool slabs, or similar material below the floor.

In each of these examples care must be taken not to exceed the structural capacity of the floor.

In situations where a floor cannot support such additional loading, the false ceiling may be supported resiliently from the walls of the room below.

A common flanking path for airborne sound transmission between rooms in older properties with timber floors, is through the space between the floor joists supporting the dividing partition. These gaps must be pugged, preferably with sand bags, along the line of the partition or alternatively, if the joists run parallel with the partition, then the partition must be constructed on top of a joist.

Impact noise from footsteps, or similar sources, can be reduced either by carpeting the floor with a thick layer of underfelt under the carpet or by a resilient layer applied between the floor boards and the joists. This latter system generally involves a system of floor boards being laid either as a series of panels fixed together with nails and counter battens, which are laid loose, or fixed through special resilient supports, on top of a resilient quilt which is draped over the top of the floor joists, or as tongued and grooved boards glued together and laid on top of a quilt laid on the existing floor. One problem that can occur with these systems is the panel edges can rub together and cause creaks. To avoid this problem sufficient gaps should be left between panels or resilient inserts used.

Commercial lightweight floors are available and if specified must be constructed in full accordance with the manufacturers instructions.

(iii) Floated Floors (Figures 17, 18, 19, 20 and photographs page 44.)

Floated floors are generally provided in studios or technical areas where there is a possibility of structure borne noise transmission from other areas. This form of construction allows one part of the building to remain stationary (and quiet) whilst other parts move or vibrate under the influences of structure borne noises.

In framed buildings of either concrete or steel, it is generally considered essential to resiliently float studios and technical

areas unless they are sited at ground level and isolated from the framework of the building.

Glass fibre blankets and polystyrene have been used extensively to support floating floors in commercial and domestic buildings of all types, but there are problems with the performance of these materials which suggest that they are of doubtful value under compression in the special case of broadcasting studios. The main problem is that the resonance of the system is in the 60-80 Hz region, which is within the audio frequency range. This is satisfactory for many building applications but is far from ideal for broadcasting studios where the low frequency limit of the audio range requires a suspension system with a natural frequency of the order of 10 Hz or less to achieve the necessary isolation.

In certain situations restrictions on loading or cost will not permit the use of a fully floated structure and the use of a lightweight floor on a resilient quilt has to suffice. The normal method of construction is to lay a 30mm blanket of high-density, non foil backed, resin bonded mineral wool on top of the existing floor surface, cover the mineral wool with a protective layer of polythene sheeting, lapped and taped at all joints, and then lay a layer of lightweight reinforced concrete on top of the polythene. The lightweight concrete must be capable of withstanding the normal impact and point loads from studio equipment, furniture and carpet fixings.

The mineral wool is turned up at the edges to avoid structural contact between the floated floor and the surrounding walls which are generally used as permanent shuttering and are themselves supported off resilient pads. Particular care has to be taken at door openings to avoid bridging.

In some instances it has been found necessary to form ducts in the lightweight concrete floor for cables from the technical skirting at the base of the wall to the control desk in the centre of the cubicle floor. To avoid bridging the floated construction it is recommended that the duct be formed in two separate building operations. Firstly the duct is formed with rigid formwork, on top of the mineral wool quilt, and temporarily fixed to the structural floor through the quilt whilst the lightweight concrete floor is laid. Secondly, after the concrete floor has cured the formwork is removed and a pre-formed duct is laid on top of the quilt and fixed horizontally into wooden inserts cast into the lightweight concrete. Duct covers may be formed in damped metal sheeting, 19mm thick Medium Density Fibreboard (M.D.F. board) or 19mm thick Multi ply. Blockboard and plywood are not considered suitably stable enough for this situation.

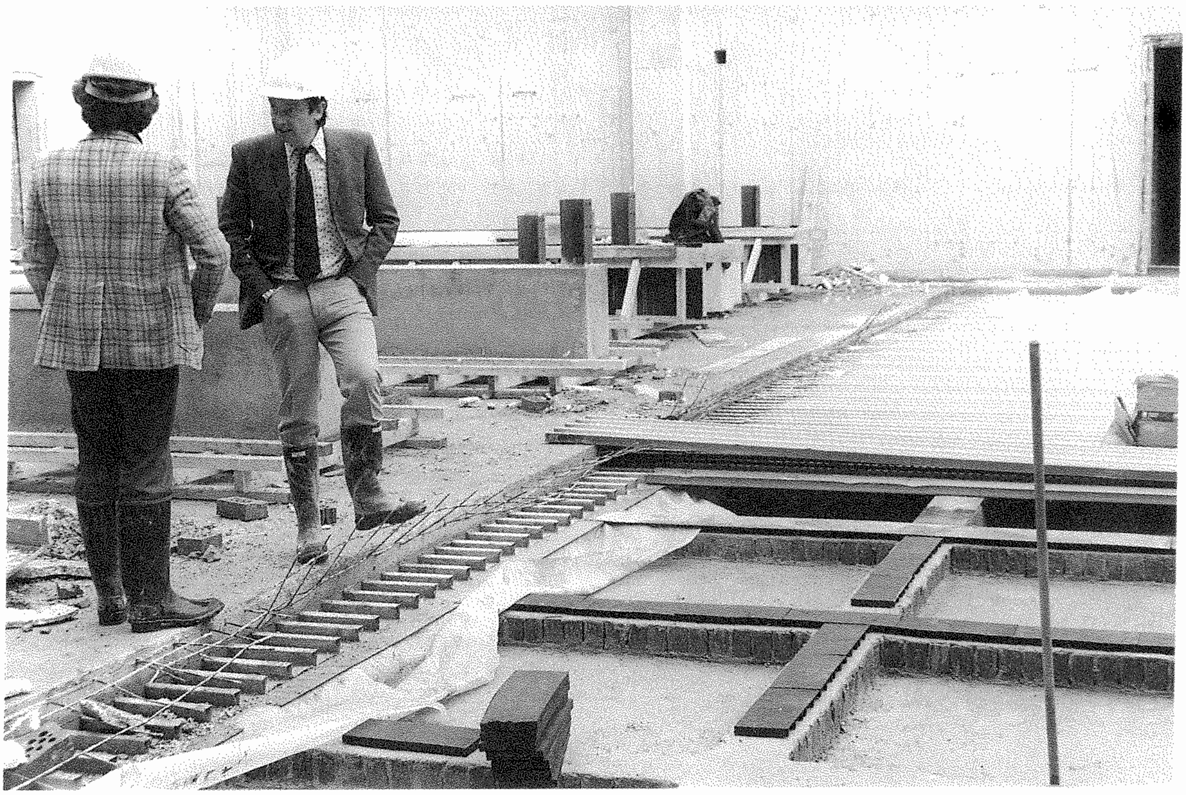
The design of vibration isolation systems more complex than those previously discussed requires specialist knowledge. The following is only given as a guide to the essential considerations.

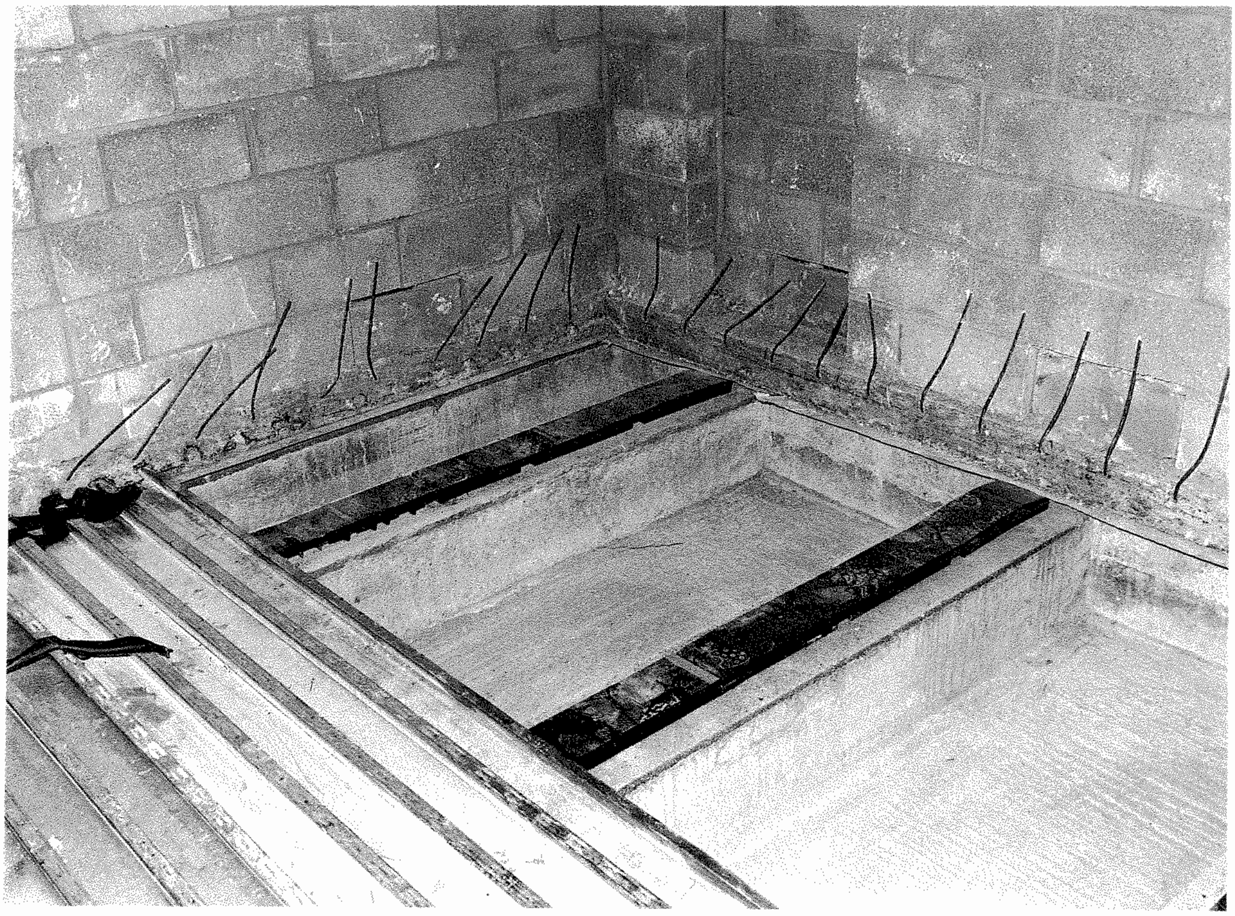
Rubber is the most commonly used material for floating structures in the acoustic design of BBC broadcasting studios and, as it is an incompressible material, it has to be allowed to expand laterally or to be used in shear for it to work. It is always used in the form of proprietary components.

To achieve the required natural resonant frequency of 10Hz or lower when a studio is mounted on rubber pads, the pads must be compressed to very near the limit allowed by the manufacturers, beyond which there is a risk that they will be permanently deformed. For this reason it is necessary to consider very carefully the difference between the maximum load and the dead load, so that the pads will not be overloaded when the studio contains the maximum number of performers, audience, etc. It is also necessary to allow for loads applied during construction, e.g., when concrete is wet, and walls and roof may be temporarily supported from a floated floor. It may sometimes be necessary to use a double layer of pads to allow for the maximum load conditions. It is, of course, essential for isolation that the pads are specified to achieve a low enough resonant frequency when the studio is almost empty, i.e., under minimum dead load conditions.

The above is a rule of thumb practical solution to achieving natural frequencies within acceptable limits.

In <u>all</u> cases the loads imposed during construction and whilst the studio is in service should be given to the supplier of the rubber isolators. They may be conveniently presented on an arrangement





Floor construction showing resilient pads on upstands and floor finishes

drawing of the floating structure marked with the separate weights per unit area of the floor, walls and roof. Should the roof of the floating structure be suspended on flexible hangers from another structure, this should be clearly detailed so that the load applied to the top of the walls can be calculated.

A ' box within a box' structure is normally constructed as follows:-

(a) Rubber Vibration Isolators covered with a protective layer of polythene are placed on the structural floor or on upstands and topped with 3mm thick (or as specified) mild steel spreader plates as detailed in figures 18, 19 and 20. The upper surface of the upstands must be trowelled level with a 10mm thick bed of mortar and sufficient time should be allowed for the mortar bed to set before the rubber pads are placed in position. Any variation in level of the upper surface of the mortar bed must not exceed ± 2mm in one metre or ± 6mm overall. An alternative to this would be to bed a metal plate on top of the upstands to the same tolerance.

(b) Lay damping in the form of 30mm thick, non foil backed, 40-60 kg/m^3 density resin bonded mineral wool on the structural floor slab between the rubber mats, isolators or pads.

(c) Lay permanent shuttering on top of the rubber mats, isolators or pads. This can be either in preformed metal sheeting or interlocking concrete planks with joints between sheets or planks carefully taped to avoid seepage between panels into the void below.

For this system to work it is absolutely essential that the air space under floor and around the edges of the rubber mats or pads is kept spotlessly clean and that there is no solid link between floated floor and the main structure.

The airborne sound insulation obtained in practice by this construction will be affected by the space left between the structural floor and floated floor. This should be a minimum of 115mm and preferably nearer 300mm.

From this point onwards the construction can be varied. Two basic systems of construction are available, namely:-

1. The system utilising preformed metal sheeting as permanent shuttering (figures 18 and 19).

2. The system utilising precast concrete planks as permanent shuttering (figure 20).

These will be treated separately.

1(d) If preformed metal sheeting is used then the next stage is to cast the lower part of the concrete slab onto the shuttering. The walls and inner roof slab of the studio can then be erected off the floated floor. The walls may be used as permanent shuttering for the concrete floor screed. In this construction it is important for the edges of the concrete slab to be temporarily shuttered to avoid spillage of concrete into the cavity between the walls.

1(e) Lay a damping layer in the form of a bituminous membrane on top of the concrete and then pour the final concrete topping and floor screed. This membrane is necessary to provide damping of the natural resonances of the concrete structure.

Where either wood-block or wood-strip flooring is used as a studio floor finish it must be bonded direct onto the concrete with no gaps between the timber and the concrete surface.

2(d) If precast or prestressed concrete planks are used as permanent shuttering, at this point the walls and inner roof to the studio can be constructed off the floated floor.

2(e) Lay a levelling screed on the concrete planks and then the damping layer in the form of a bituminous membrane on top of the concrete. Finally cast the structural topping and floor screed onto the damping membrane using the outer walls as permanent shuttering to prevent concrete spillage into the cavity. The damping layer is necessary to provide damping of the natural resonances of the concrete structure. Where either wood-block or wood-strip flooring is used as a studio floor finish it must be bonded direct onto the concrete with no gaps between the timber and the concrete surface.

Flexible wall ties may be used to provide structural stability for the floated walls provided that the ties are kept spotlessly clean. (See section 2.3(i)).

Any ducts or pipework entering floated structures from other areas must either have flexible couplings where they pass through the cavity, or pass through a resilient sleeve in the wall to avoid bridging.

Holes through a floated floor should be avoided, but if absolutely essential, they must be made good with sand-bags or similar mass material. The use of the mineral wool infill alone for filling holes or gaps is to be avoided, but where it is used it must be rammed tightly into the hole or gap and a layer of plaster, cement or mastic applied to the outer faces. This must only be used for small holes or gaps of not more than 6mm.

Large holes must be made good throughout the thickness of the structure with solid material taking care not to bridge the cavity.

(iv) Modular or Suspended Floors

Modular or suspended floors supported on a framework or proprietary system are usually provided in control and apparatus areas associated with television as they provided unobstructed, easy access runs for cables between technical areas. These types of floors are not acceptable for radio studios or cubicles as the under-floor void can affect the room acoustics and the floor tiles themselves are prone to creaking as people move around within the area.

Various commercially designed computer or modular floors with slim supporting upstands have the advantage that initially, they have a good appearance and afford easy access to the cables. In practice, however, it has been found that many examples of this type of floor are unsuitable for BBC purposes, principally because after a lengthy technical installation period the supports can become deformed and make the removal and replacement of floor panels extremely difficult. This is often due to the lengthy drawing of heavy cables through the forest of vertical supports using them in some cases as the fulcrum of a turn. Depending on the type of floor finish, the panels can also be noisy when subjected to impact noise such as footsteps.

It is recommended that suspended floors should be designed or selected by the Project Architect to suit each situation. This design may take the form of a 'builders work' detail comprising traditional sleeper walls and piers with joists and panels on top. Alternatively it can be constructed in an interlocking metal framework similar to that used extensively at the Television Centre, or other buildings where more stringent fire regulations are applicable.

At the completion of the technical installation it is essential that all holes under the computer floors through supporting walls are fully pugged or even bricked up around the cables to ensure that there is no acoustic breakthrough and to prevent the spread of fire from one area to another.

Where modular or suspended floors are provided in areas adjacent to studios or technical areas it is important that the support system is not linked in any way to the structure enclosing the studio or technical area. This particularly applies to corridors with modular floors where the edge panels have, in some instances in the past, been supported off a frame or bracket fixed to the wall. This practice must be avoided at all costs and floor panels or framing must be provided with resilient pads where necessary when the likelihood of transmission of sound exists.

Where a suspended floor is designed simply to raise the existing floor level it is important that all supporting members are designed to incorporate resilient pads to avoid impact noise being transmitted into any noise sensitive areas below.

2.5 Roofs and Ceilings

There are four types of roof or ceiling commonly used in the construction of studios and they are as follows:-

(i) A structural slab usually formed in concrete

(ii) A roof to a 'box within a box' structure

(iii) A fixed or suspended roof or ceiling which is designed to improve the sound insulation of an existing structure

(iv) A suspended acoustic tile ceiling.

In addition to the above four types of roof or ceiling there are two other items of construction often present in studios or technical areas which must be borne in mind as their presence can sometimes give rise to acoustic problems. These are the suspension systems for acoustic tile ceilings and lighting grids which are covered in Section 3.11 and 3.15.

(i) A Structural Slab Roof

An external roof to a studio is normally designed to achieve an average insulation of 65 to 70 dB over the frequency range 100 Hz to 2.5kHz. It must be constructed precisely to detail with no structural weaknesses and, if formed in concrete, must be properly vibrated. To provide this degree of insulation it is usually necessary to construct the roof as a double-skin structure with a substantial cavity between the skins. The lower roof, generally formed in concrete, acts as the studio ceiling and the upper one, sometimes constructed in concrete and sometimes in channel reinforced woodwool slabs topped with asphalt, is laid to provide falls for the roof finish.

The cavity between the skins should be acoustically damped with a 30mm thick layer of non foil backed, 40-60 kg/m^3 resin bonded mineral wool and any upstands, supporting the upper slab, topped with approved rubber anti-vibration pads with 3mm thick mild steel spreader plates.

In some situations it may be necessary to introduce attenuated air vents to the void between the slabs to avoid condensation occurring.

Holes through a roof should be avoided but where they are absolutely essential for services etc., attenuators or casings must be provided which give similar insulation to that of the structure being penetrated. Any gap around the duct or pipe must be completely filled right through the slab. A surface layer of plaster or cement on either side of the structure is not sufficient. For conduit a cement-sand grout will penetrate around the pipes better than a normal mix.

Where ducts or pipes pass through both structural slabs appropriate precautions must be taken to avoid mechanical coupling of the slabs either by the introduction of flexible sections or resilient sleeves.

(ii) A Roof to a 'Box within a Box' Structure (Figure 20)

In the case of 'box within a box' structures an inner roof has to be provided to give adequate airborne and structure borne insulation from the main structure. This roof, generally formed in one or two layers of pre-screeded, channel reinforced, woodwool slabs should be supported off the floated walls and bedded in mastic at the ends. The woodwool slabs are generally laid with the pre-screeded surface on the upper face and the underside rendered or plastered in situ. If they are fixed to the main structure in any way then resilient hangers must be used.

All resilient hangers together with any flexible sections or sleeves around ducts or pipework must be specified by the acoustic consultant and installed precisely in accordance with the manufacturer's specification. (See also section 1.3).

Where spans exceed 3.3m some woodwool slabs are delivered with the channel edge reinforcement in continuous lengths but with the woodwool sections in 2 or more lengths. Under these circumstances the butt joints between the ends of the woodwool sections must be filled with mastic.

Mastic must also be used to fully seal the joints between the sections of channel reinforcement where woodwool slabs butt up alongside each other.

Under most circumstances a single layer of woodwool slabs will suffice but where impact noises are generated in the structure over a studio area, it is often essential to provide higher sound insulation than can be achieved with a single layer of woodwool. In simplistic terms the upper floor slab becomes a noise generator upon impact and a single layer of woodwool does not provide sufficient airborne sound insulation to cope with the resultant noise level. Therefore a second suspended layer of woodwool has to be provided.

If possible, holes through a woodwool roof should be avoided, but where they are essential for services etc. attenuators or casings must be provided which give similar insulation to that of the structure. Flanges must be provided where necessary to avoid the woodwool crumbling where it has been cut. Any gap around the duct or pipe must be completely filled right through the slab. A surface layer of plaster or cement on either side of the structure is not sufficient. For conduit a cement-sand grout will penetrate around the pipes better than a normal mix. Where ducts or pipes pass through both structural slabs in a floated 'box within a box' structure appropriate precautions must be taken to avoid mechanical coupling of the slabs.

Where a woodwool slab ceiling is suspended over technical areas it is essential that the walls separating the areas be carried up through the void to the underside of the structural slab above. This is described in Section 2.3(i) para. 7.

(iii) A Fixed or Suspended Roof or Ceiling

Improvement to the sound insulation of existing structures generally necessitates the introduction of one or more additional structural layers being suspended above or below any area scheduled for use for broadcasting purposes. This is essential to reduce any airborne or structure borne noises generated either above or below the studio and transmitted through or via the existing structure.

The degree of airborne sound insulation that can be achieved in this situation is totally dependent upon the loading capacity of the existing structure. Normally the type of construction suitable for this situation falls into two categories.

Firstly where an existing structure is substantial and capable of carrying reasonable load, pre-screeded, channel reinforced woodwool slabs should be suspended above and below any proposed studio area to reduce noise transmission from the upper or lower floors. The woodwool slabs are generally laid with the pre-screeded surface on the upper face and the underside rendered or plastered insitu. The woodwool slabs can be supported off the structural walls but should be totally independent of the existing floor and ceiling structures. Should any support be required from the existing floor or ceiling slabs, resilient hangers must be used.

Secondly where a studio is formed within a domestic type structure it is not always possible to use additional woodwool layers to improve the sound insulation due to weight limitations. In this situation a lightweight ceiling formed in Camden construction (see figure 15) will have to suffice.

Where a domestic tile or slate roof occurs over a proposed studio area it is probable that noise from road or air traffic or other sources will penetrate into the studio via the roof and ceiling unless the whole structure is significantly improved. The introduction of mineral wool or fibreglass blankets for thermal reasons does not significantly improve the overall sound insulation. The only way to reduce road or air traffic noise is to increase the overall mass of the roof structure by the introduction of a combination of heavy layers and air spaces in the form of boarding or plasterboard layers within the roof space.

(iv) Suspended Acoustic Tile Ceilings

Suspended acoustic tile ceilings can provide a degree of sound insulation in their own right. This is particularly beneficial when a ceiling is suspended below an air-conditioning duct as the additional sound insulation provided by the acoustic tile ceiling helps reduce any noise breakout via the duct walls into the area below.

The degree of sound insulation provided by a suspended acoustic tile ceiling is dependent upon its actual mass and porosity but generally speaking approximately 5 dB at 500 Hz and 10 dB at 2 kHz and upwards can be expected.

This sound insulation should also be taken into account when cross talk attenuators with an acoustic tile ceiling below them are being designed or selected.

2.6 Staircases and Ramps

Staircases or ramps must not be connected in any way to a structure enclosing a studio or a technical area unless adequate precautions have been taken to eliminate any interference

caused by structure borne vibration from footsteps or other impact sources. This problem is generally overcome by the provision of cavity walls and resilient materials within the construction or simply by the provision of an impact absorbing covering e.g. carpet on underfelt, to the surface of the staircase or ramp.

In the case of an effects staircase provided within a Drama studio it is important to note that where different sound effects are required, for example, from wood, metal or concrete stairs, each section of the staircase must be constructed independently as a complete staircase in its own right.

A narrow gap should be provided between each staircase which may be packed with a resilient joint filler to avoid accidents.

If this is not done then mechanical coupling of the different sections will cause them to all sound substantially the same.

2.7 Studio Doors (Figures 21, 22, 23 and 24)

These are divided into two basic categories

(i) Personnel Doors
(ii) Television Doors

(i) One of the main requirements in the design of personnel doors for use in studios relates to the method of operation. The majority of overseas broadcasting organisations accept operation by latch closers of various types but, for safety reasons, these are not permitted by the BBC. A system has had to be provided which closes the door using a spring door closer operating in conjunction with a magnetic seal.

The solution developed in 1962 by the BBC, permits the door to be closed by a spring type door closer with the final sealing being provided by a proprietary magnetic strip. This is fixed to the door jambs and head, and pulls out when the door closes to make contact with a mild steel strip set into the door itself. This provides a reasonably efficient, air tight seal but to work in a satisfactory manner it is essential that the magnetic seal is fixed so that it is free to move within the rebate in the door frame, particularly at the bottom of the jambs where it is often recessed behind, and consequently trapped by, the threshold. It must be adjusted carefully so that the seal and the mild steel strip make complete contact all round the sides and head of the door. It is also essential that the seal is set fractionally in front of the face of the frame to avoid metal to metal impact on closing. It should not be significantly compressed. Such incorrect fixings have in the past led to mechanical damage to the seals.

The magnetic seal used in this door design is similar to that manufactured for domestic refrigerators. The magnetic material is barium ferrite in a p.v.c. rod. The seal is set into rebates in the jambs and head of the door frame and is fixed in place with non ferrous screws through a thin aluminium strip. An aluminium trim set into the frame adds mass to the seal and also prevents lateral movement without restricting the sealing action. The magnetic strip has a strong polarity and it is essential that it is positioned the correct way round. The side without the bevelled corners i.e., the flat side should be towards the mild steel strip.

Where a door with magnetic seals is required to act as a fire door then intumescent seals may be set into the door frame without affecting the acoustic performance of the door.

It is essential that the spring door closer has a reverse check action which initially allows the door to close quickly and then slows it down over the final stages of closing. This is the reverse of the normal closer operation where the closer is required to accelerate over the final stages to close a door latch or lock. Latches must never be fitted to doors serving BBC studios or technical areas where live microphones or operatives will pick up the 'clicks' made by the latch on closing. Generally, only the external door to any sound lobby should be fitted with a lock and all other doors should be fitted out with only pull handles and push plates. Key holes must never be cut into doors opening direct into studio areas.

Door closers must be selected with care making sure that the correct type is specified for the weight of door, particularly with lead cored doors, and that they are readily adjustable and require minimal maintenance. Correct adjustment is

not always obvious; with at least one approved door closer the length of the closer arm is critical. During the technical installation the acoustic doors are often wedged open for lengthy periods and it is advisable to disconnect the closer arm to avoid the door becoming twisted and requiring re-hanging. Similarly it is recommended that fitting threshold seals only after the technical installation has been completed.

At the threshold a magnetic seal was originally set into the bottom of the door itself but this detail proved to be unsatisfactory due to the fact that the seal was easily damaged and the door had to be taken off its hinges each time to replace it. An alternative detail was devised which uses an aluminium 'h' section extrusion which incorporates a neoprene rubber compression seal. This seal, which is rebated into the face of the door, closes onto a sloped hardwood threshold and has proved to be reasonably successful over the years. One problem that has occurred regularly however is that the rubber insert has 'rolled out' with contact with the pile of a new carpet despite attempts to hold the rubber in its aluminium extrusion with glue. Another, and more successful, solution to this has been to raise the threshold itself fractionally above the carpet surface, this is illustrated in figure 24. Care must be taken, however, to avoid introducing a step which makes it difficult for anyone moving heavy studio equipment in and out of an area.

At the time of going to press an alternative threshold seal which rises up into a rebate behind the kicking plate at the bottom of the door as soon as the door commences to open is undergoing tests.

The door itself should be constructed either as a solid cored door or with a lead insert, both set into hardwood frames to the dimensions and details shown in Figures 21, 22, 23, and 24.

When lead cored doors are used they should be double tongued all round. Solid drawn 100mm or 125mm brass butt hinges, with either double steel or phosphor bronze washers, with steel pins are recommended for use on all acoustic personnel doors. Solid cored doors should be hung on at least 1½ pairs with 2 pairs used on lead cored doors and on the wide leaf of double personnel doors.

All hinges for lead cored doors should be bolted through the hardwood frame and plated.

The positioning of the upper two hinges close together near the top of the door at the point of maximum stress has proved to be beneficial to the stability of lead cored doors.

Areas of glazing in acoustic doors should be kept to a minimum. The thickness of glass illustrated in figures 21, 22, 23 and 24 is only applicable when the area of glazing is confined to the 200mm square portholes shown or up to a maximum area of $0.05m^2$. Where the glazing area is increased the glass thickness must be increased accordingly.

The siting of doors to studios and cubicles is referred to in Section 4.4. It is important to check that at least one door is <u>wide enough</u> to allow equipment and control desks to pass through them, as damage to doors or frames, or disturbance of mastic joints will impair the acoustic isolation. In certain situations it may prove necessary to specify double or "door and a half" doors as shown in Figure 23.

In BBC studios the planning of personnel doors usually allows for an acoustically treated sound lobby to be provided for each studio suite. The sound insulation value of each separate door to a lobby need not therefore exceed 30 dB average sound pressure level difference over the frequency range 100 Hz to 2.5 kHz. This can normally be achieved with a 50mm thick, solid cored, half hour fire door with good acoustic seals.

In situations where space is not available for a sound lobby, access has to be provided direct from one area to another. Here it is acceptable to use one lead cored and one solid cored door, both opening outwards and fixed to the outer faces of the wall construction thereby providing the maximum possible acoustically treated airspace between the doors.

Approximately 60 dB average sound pressure level difference over the frequency range 100 Hz to 2.5 kHz can be achieved for such a combination of doors in a double 112mm brick or triple Camden wall. This is generally acceptable for Talks/Continuity Studios to their control Cubicles.

A problem associated with the design of sound lobbies and double doors is that the closure, or more likely the rapid opening, of one of the doors causes a build up of air pressure within the lobby resulting in one or more doors in the lobby being forced open to release the pressure. This pressure is created by the moving door acting as a piston over its thickness within the door frame. One solution to the problem is to provide the lobby with a vent of some form which will eliminate the pressure, without degrading the sound insulation to any great degree. Proprietary acoustic air bricks are available for such situations but it has often proved difficult to site them in the ideal position for maximum effect. The BBC have conducted further experiments into the problem and have come up with the simple, but extremely effective, solution of splaying the leading edge of the door and frame as illustrated in Figure 24. Where locks are required to be fitted to this design there are two basic alternatives, firstly to use a special lock with an angled locking plate or secondly to block out a short section of the angled edge to take a standard lock.

Where a carpet finish is specified to a door to reduce sound reflections, the door should be provided with hardwood lipping or surround to the carpeted area.

All timber must be completely bedded in mastic where the door frame butts up to brick or concrete surrounds. Architraves fixed on either side of a frame in an endeavour to hide cavities between the door frame and the edge of the wall, where it has been packed out, will be unsatisfactory as high frequency sound will find its way through the gaps. If the frame has to be packed out for any reason the gap should be filled with cement mortar or plaster before the mastic is applied.

Care must be taken to avoid bridging cavities in any structure, floated or otherwise, and any sealing of cavities must be carried out with a flexible connection where it makes contact with one leaf so that the two leaves are not rigidly tied together.

If timber acoustic doors are installed in a building before it is completely weatherproof, it will be necessary to seal up all openings and provide temporary heating within the building to prevent movement of the timber doors within their frames due to damp site conditions. Such movement could result in permanent damage to the doors, necessitating their replacement.

(ii) Doors for television studios are provided for access to scenery runways, scene docks, scenic workshops, stores and technical areas associated with the studio. Generally these large doors require a higher standard of sound insulation than is provided by personnel doors. Television doors are normally purpose-made in steel for each installation and are required to provide an average sound insulation of at least 45 to 50 dB over the frequency range 100 Hz to 2.5 kHz. The doors are usually provided either as a hinged pair of doors fitted within an opening or as a single leaf panel fitted to the face of the wall and operated as a lift and slide door by an overhead mechanism. In both instances the frames must be designed and installed so as to avoid any reduction in the overall sound insulation performance.

To achieve the specified sound insulation using pairs of hinged television doors it is essential that compression seals are provided all round the doors. These seals, with the exception of the threshold seal, are usually formed from rubber extrusions set into single or double rebated frames and door edges and are compressed by the action of the locking mechanism. One leaf generally being shut first with shoot bolts to hold it rigidly in place and the second leaf compressed and closed against the first leaf. The main problem with this type of door is to provide satisfactory air tight seals around the door as pairs of hinged doors have inherent weak points in their design, namely at the four corners of the overall door opening and the top and bottom of the centre seal. These points all require careful attention to design and installation to ensure that the compression seals are working correctly. If the seals do not work correctly the measured middle and high frequency sound insulation will be dramatically reduced.

The requirement for freedom of movement of scenery in and out of a television studio rules out a raised threshold. Consequently the bottom seal has to be designed to compress or seal directly onto the flat studio floor surface. This can be achieved by a number of methods but it is important that when the door is closed the threshold

seal is compressed along its full length. Whilst the door is being opened the seal must rise clear of any nails, screws etc. that may be on the studio floor and could damage the seal.

'Lift and slide' doors were originally developed to seal off refrigeration rooms, with good seals being an essential pre-requisite of the operation of the door. The actual door panels were developed to be more thermal than acoustic. Over a period of years the seals have remained as efficient as ever but the panels have been re-designed to achieve higher sound insulation ratings of the order of 50 dB average over the frequency range 100 Hz to 2.5 kHz.

The overhead lift and slide mechanism can be supplied for either electrical or manual operation.
Because the door panel lifts clear of the floor during its operation, there is little risk of damage to the threshold seal by screws, nails etc. on the studio floor and the seals around the perimeter of the door panel only come under compression with the final action of the door mechanism. It is advisable to operate this type of door electrically as a 'fail safe' mechanism can be incorporated in its design to avoid accidents whilst the door is in operation.

An alternative design to those discussed earlier which has been used successfully in European studios, but to date has never been installed in BBC studios, is for the door to be designed as a single leaf panel which is moved vertically. Acoustic sealing around the perimeter is achieved by absorption, with the door panel itself being oversized considerably in relation to the opening dimensions and being raised or lowered in an acoustically absorbent cavity. The panel itself is constructed so that there is only a minimal gap between the door panel and the absorbent surfaces of the cavity.

In this design threshold sealing is provided by rubber seals, fixed to the underside of the door panel, which are compressed onto the studio floor surface by the weight of the door when it is closed. Where the design allows for the panel to be lowered into, say a basement under a studio, then the door head becomes the threshold of the opening when the door is open.

2.8 Windows (Figures 25, 26, 27 and 28)

(i) Radio Studios : Observation Windows

Observation windows are provided between all types of BBC radio studios and their control cubicles and are constructed in double, triple or even, in rare cases, quadruple glazing.

Sight lines from a control cubicle to its associated studio (see figures 47 and 48) normally determine the size of an observation window between the areas but, because glass is an acoustically reflective surface, it is advisable to keep the window size to a minimum. Recommendations have been made for maximum window dimensions and in a local radio or a talks studio the actual glass size should not exceed 2.44m width and 0.85m height with a cill height from the floor of 0.9m and a head height of 1.75m.

As a general rule BBC observation windows are specified as triple glazed using a central 10mm thick pane of glass and two outer panes of 6.5mm glass; the reason for the differing thicknesses of glass being to reduce the effect of resonances. Where larger windows are unavoidable it is often necessary to increase the thicknesses of the individual panes again to reduce the effects of resonances in the glass.

To achieve satisfactory sound insulation through a studio observation window the minimum spacing between the panes of glass should be 200mm. The reveals to the space between them must be acoustically lined with mineral wool or acoustic tiles. The construction shown in figures 25 and 26 allows for the occasional removal of the outer panes for cleaning purposes and incorporates a light rubber gasket behind the aluminium section or extrusion to ensure that the window frame is fully sealed to the opening each time a pane of glass is replaced.

Where lesser standards of sound insulation are required, double glazed observation windows are normally specified. These are illustrated in figures 27 and 28.

Recent research by the BBC Research Department has proved that angling the centre pane of glass in an observation window is a piece of unsubstantiated acoustic folklore

and no acoustic benefits accrue from this practice. However, by keeping all three panes of glass vertical, optical reflections from the lights, etc., are reduced. Therefore all observation windows in BBC studios are now installed with all panes vertical unless two observation windows in a studio or technical area are sited opposite to each other or in other situations where flutter echoes may occur. (See section 3.4). One example of that is where windows within a room form a triangle (see figure 36). In these situations one of the outer panes of glass should be angled by approximately 10 degrees from the vertical or alternatively both opposing panes should be angled 5 degrees out of parallel to eliminate flutter echoes. The direction of the angle should be selected to minimise reflections from light fittings.

In a situation where an observation or external window is opposite a hard reflective surface, such as a door, then either the window should be angled by 10 degrees or the other surface treated with carpet or similar high frequency absorbing material.

If a blockboard lining is used to frame a window opening, any gap behind the blockboard must be completely filled particularly if the blockboard is fixed to battens. In this situation the space between the battens must be infilled completely with sand and cement screed and plastered over. If the blockboard is fixed directly to the structure then any gaps behind it must be filled with 1 : 1 mix sand cement levelling bed and a mastic seal.

All observation windows should be constructed precisely in accordance with the standard details, with all compression seals fully compressed and all timber framework <u>bedded throughout</u> in mastic where it butts up to brick or concrete surrounds. This is an important point which has often been omitted in the past and has only come to light when complaints have been received of poor insulation at high frequencies. On inspection it has been found that the usual cause is that the timber has shrunk and pulled away from the structure leaving a gap or that only a thin layer of mastic has been applied after the building work has been completed. <u>Remember sound will find its way through the slightest hole</u>. Care must be taken to avoid bridging any cavity whether in a floated construction or not.

(ii) <u>Television Studios : Observation Windows</u>

Observation windows between Television Studios and their control galleries are often obscured by cycloramas or scenery and consequently the demand for expensive observation windows is getting rarer with the producer's link with the studio floor being via the cameras and their monitors and the studio or talkback microphones.

Within the gallery itself a visual link between the producer and the lighting director is essential and a double glazed observation window is provided between these rooms. In the case of the sound gallery the acoustics of the room are important to the audio director and therefore the area of glass is kept to a minimum. Any window in the sound gallery should be triple glazed to provide acoustic separation.

The construction and design principles are as outlined in the previous section 2.8(a).

(iii) <u>External Windows to Studio Areas</u>

It has become increasingly popular over the past few years for operational staff to ask for external windows to be included in the design of Continuity or Local Radio studios or their control cubicles. Such windows should be triple glazed using differing thicknesses of glass with large acoustically treated airspaces between the panes.

Where studios are constructed in existing premises, it is normal practice to seal up the existing external window and construct two new inner panes of 12.5mm and 10mm glass spaced at least 200mm away from the existing pane and at least 150mm apart. The cavities must be acoustically lined at the jambs and head with the cill being left untreated to cater for any condensation problems.

The main difficulty with the use of external glazing in studios is that low frequency noise from buses and other heavy road vehicles will penetrate the areas via the external windows and will be clearly audible. This may require electronic bass cuts to be installed in the microphone circuits to avoid the noise being broadcast. External windows are not permitted in BBC Drama or Music studios for either Radio or Television.

(iv) Offices

External noise from road vehicles, aircraft and other sources is often troublesome for occupants of offices, causing loss of concentration and consequently a reduction in efficiency and output. Many BBC offices have had to be fitted with double glazing to reduce the noise to an acceptable level. Ideally, sealed window units constructed along the same principles as studio observation windows would be the most satisfactory solution, but, unfortunately they are expensive and generally lead to the need for some system of forced ventilation. The BBC has evolved a design for existing structures, which provides ventilation and also a significant reduction in noise level. The design is based on an openable external transom window and an openable bottom unit on the inner leaf which gives the occupant of the office the option of reduced noise levels, ventilation or a combination of the two.

The same principle may also be applied to horizontal and vertical sliding windows.

2.9 Modular Studios

The concept of modular studios originated from basic factory-made industrial enclosures designed for the protection of machinery or ventilation equipment.

The original industrial enclosures, which are still in regular production, are made from prefabricated, composite pressed metal panels, approximately 100mm thick, which can simply be joined together at the edges to form the walls and roof of an enclosure. The standard panels can be designed to span reasonably long distances with rolled steel joists being used to reduce the lengths of roof panels. The basic panels are very plain, simply comprising solid galvanised metal sheets on the external face and perforated galvanised sheets on the internal surface over a mineral wool infill.

For studio applications, the designers of the modular systems have taken the original panel design, increased its mass to improve the overall sound insulation and then covered the perforated metal sheet with stretched fabric or other decorative internal finishes. At the same time they have incorporated tuned panels to widen the range of absorption from the internal finishes and control the overall acoustic response of the studios. Special panels for doors and windows have also been designed to enhance the system.

By providing panels which perform both as an enclosure and an acoustic lining, there is no need to add further acoustic treatment such as modular absorbers to the internal surfaces of the studio. This significantly reduces the overall size of the enclosure when compared to traditional construction.

A studio is normally constructed from two such enclosures, one inside the other, giving a complete 'box within a box' construction. The floor of the inner box is resiliently mounted using either metal floor panels or a concrete slab supported off anti-vibration mountings.

The low frequency sound insulation provided by this form of construction is similar to that achieved by double Camden construction and consequently is not ideal. To improve this between say a Talks or Continuity Studio and its Control Cubicle at least a triple leaf wall construction should be used to separate the areas, with the central wall supported off the structural floor slab and carried up to the structural roof slab and the two other walls floated off the respective resiliently mounted floors.

Whilst the modular studios are normally installed by the manufacturers, care must be taken by other trades working in adjacent areas to ensure that computer floors, conduits etc. are not fixed to the outside of the studio walls, thereby bridging the anti vibration mountings.

2.10 Outside Broadcast Vehicles

Whilst only a small number of BBC Outside Broadcast vehicles is used specifically for programme origination, the principal function of such vehicles is to provide mobile control rooms and production facilities for both the Radio and Television Services at events held away from studio centres. The vehicles are often used in noisy environments and consequently sound insulation to the outside world is an important factor in their design.

Statutory limitations on vehicle weight and size more or less dictate the type of

materials which can be used to construct the walls, floor and roof of any vehicle, with any reduction in mass of the structure being immediately used to increase the load bearing capacity of the vehicle itself for equipment, while a reduction in wall thickness will increase the working space within it. Restriction of wall surface density (mass per unit area) will on the other hand limit the degree of sound insulation that can be achieved while the restriction of wall thickness precludes the use of double leaf construction.

Such restrictions on the mass of the structure will limit the sound insulation that can be achieved particularly at low frequencies. Consequently the problems presented to the vehicle designer are considerable.

Over a period of years the BBC Research Department have, in conjunction with vehicle manufacturers developed a lightweight sandwich construction which provides a high degree of sound insulation for the walls and roof.

Vehicle walls have to be thermally insulating as well as sound insulating and until recently it has been normal practice to accept the sound insulation provided by a thermally insulating wall constructed of lightweight materials which generally consisted of layers of expanded polystyrene and aluminium sheeting. Recent laboratory tests have shown that a dip in sound insulation values may occur in the mid-frequency range when rigid foams are used. The reason for this is that the compliance of the foam and the masses of the two cladding surfaces form a resonant system with an impedance lower than that normally provided by the overall surface density of the partition. Some damping may be provided by frictional effects if the foam is in the form of loose slabs, but the damping is reduced if the foam is bonded to the cladding surfaces.

The earlier design of vehicle wall construction consisted of two layers of expanded polystyrene with a layer of aluminium sheet sandwiched between them and the 2 outer surfaces comprising of a layer of aluminium sheet and one of formica. This construction produced 31 dB average sound pressure level difference over the frequency range 100 Hz to 2.5 kHz whereas the new wall construction, comprising of two layers of mineral wool with a sheet of sound barrier mat between them and outer surfaces of plywood and glass reinforced plastic, provides 38 dB average over the same frequency range. Approximately half the increase in sound insulation may be attributed to the increased surface density resulting from the inclusion of sound barrier mat, the rest being caused by the different materials used in the two constructions. Without the sound barrier mat the surface densities of the two types of construction are approximately the same.

2.11 Mechanical Services (Figures 30, 31 and 32)

Ventilation systems are often the cause of the ingress of airborne noise into a building and the reasons for this are mainly covered in Section 1.3.

Ducts passing through a wall, floor or roof slab not only require cross talk attenuators inside the duct at the point they pass through the construction but they require the structure around them to be made good after their installation. In an ideal world sections of ventilation trunking would be built into walls, floors or ceilings during their construction but, for a variety of reasons, mainly one of damage to the ductwork, this is not feasible and a hole has to be formed or cut in the structure which has to be large enough not only for the duct to pass through the hole but with allowance for its flanges as well. In certain situations the hole has to be formed large enough for the duct to be manoeuvred into position at an angle.

All this means that once the duct is in position there is a gap all round the outside of it which must be made good. Figures 30, 31 and 32 show typical details of how this may be achieved.

In some installations a timber lining, which is fully bedded in mastic, is constructed around the duct and then the space between the duct and the lining is packed with mineral wool covered with a loose flange. This detail must not be used for gaps in excess of 6mm and the structure must be made good before the lining is fitted.

In a situation where a duct passes through a structure and is sited close to another structure, for example a duct passing through a wall only a few centimetres below the roof or ceiling slab, it is extremely difficult to seal around the duct unless great care is taken with the detailing at the design stage and close liaison exists between the ventilation engineer, the clerk of works and the contractor during the construction and installation period.

The same applies when two or more ducts are placed close together with a small space between them.

Equipment containing moving parts is generally mounted on either inertial bases or anti vibration mountings to avoid structure borne transmission of sound and it is extremely important that any bridging across a resiliently mounted system is avoided. This point is covered in more detail in Section 1.3 (iv) c.

Induction units around the perimeter of a building invariably cause breakthrough of sound between rooms. This point is covered in more detail in Section 1.1.

At all openings in walls where timber is fixed to brickwork or concrete for framing up openings for ductwork the timber must be fixed as described in section 2.1(i).

2.12 Technical Services (Figure 33)

Wherever practicable any cable ducts or conduit passing from one area to another should be taken outside the rooms concerned into a quiet area, such as a sound lobby and pass from there into the second area. In some instances plastic or earthenware rainwater pipes can be cast into the structure to provide cable routes between areas. Figure 33 illustrates typical studio layouts showing the preferred routes for technical and electrical ducts.

One other sound transmission route of which the designer must be aware is vertical ductwork which has thin walls or doors and passes from area to area. To improve the insulation through these and other ducts they must be filled with sand or mineral wool pugging which must completely fill the hole in the structure.

Loudspeakers should not be supported on partition walls by shelves or brackets as this will transmit sound energy into the wall and consequently into the adjacent area.

Computer floors (access floors) are generally provided in control rooms and technical areas associated with television studios to provide flexibility for cable runs, but they are not acceptable in radio studios or cubicles. They may be used in sound lobbies provided that they are in no way connected to the surrounding structure other than by upstands from the structural floor. This allows the under floor void to be used as a 'distribution box' to feed cables into respective areas. (See section 2.4(iv)).

Where computer floors are used, it is essential to 'pug up', or even brick up, holes under a floor upon the completion of the technical installation to achieve good sound insulation and fire protection between areas.

2.13 Electrical Services (Figure 33)

It should be clear from the preceding sections of this chapter that great care must be taken in the design of the electrical services to ensure that the acoustic design is not compromised.

In providing runs for services the architect can create paths through which noise can travel from room to room; examples of this are skirtings or cable ducts which pass through a structure. These ducts are generally formed in pressed steel or plastic and are often of generous size. It is essential that they are filled, after the cables have been installed, with a material of substantial mass, usually in the form of pugging, at the point where they pass through the structure; otherwise all the time and money spent on elaborate constructions will be wasted.

Close liaison between the project architect, the acoustics consultant and the electrical engineers at an early stage of a project is essential to determine the nature of the acoustic requirements and to ascertain associated constraints on the electrical installation. In order that layouts can be finalised in a satisfactory manner, it is essential that the details of all the equipment layouts are provided at an early

stage. This includes the siting of the loudspeakers in relation to their method of support and, most important of all, the routing and size of all cable ducts. In some instances last minute decisions about the routing of cable ducts have had very serious effects on the sound insulation of the structure enclosing a studio or technical area. It is therefore extremely important that the routes of all ducts be carefully planned and notified to the architect concerned for inclusion at an early stage on the drawings. In designing the layout of technical ducting care must be taken to avoid direct routes between, for example, a studio and cubicle as such a route could degrade the sound insulation of the dividing wall.

Wherever practicable any cable ducts or conduit passing from one area to another should be taken outside the rooms concerned into a quiet area, such as a sound lobby and pass from there into a second area. In some instances plastic or earthenware rainwater pipes can be cast into the structure to provide cable routes between areas. Figure 33 illustrates a typical studio layout showing the preferred routes for technical and electrical ducts.

The number of conduits or ducts passing through any wall construction in a technical area should be kept to a minimum and where possible should be installed prior to the completion of the wall construction. This will enable the building contractor to make good around the outside of the conduit or ductwork to the standard of the remainder of the structure. Where this is not possible, as in the case of very small holes, not greater than 6mm, mineral wool pugging or mastic may be used.

The positioning of any hole requiring cutting or drilling should be clearly marked on the wall or structure and approved by the resident Engineer or Clerk of Works prior to the cutting being carried out by the main building contractor.

To limit the sound transfer through conduit it will be necessary to ram in mineral wool or mastic tightly around the cables. In the case of ductwork, pugging bags containing dry sand or high-density mineral wool should be rammed tightly into the duct after the installation of the wiring is complete.

The pugging must fill the entire hole in the duct and be the full thickness of the structure. To pug a hole or duct the objective is to fill the majority of the hole or duct with bags filled or partially filled with dry sand, then to ram in smaller bags, filled with high density mineral wool, which mould themselves round the cables and corners and seal the duct.

Where conduit or ducting passes through resiliently mounted building structures or a cavity wall structure they must always be provided with a flexible length or sleeves to avoid bridging. In the case of trunking this may be achieved by the use of a sleeve type connection with one section free to slide within the other. The larger section is lined with non-flammable felt or an approved alternative resilient material, to seal the gap and eliminate the possibility of sideways movement. Sections of flexible conduit are usually very short and care must be taken to ensure that the flexible section is not unduly compressed but is left at its optimum length thereby retaining maximum flexibility.

Electrical conduits, fittings and accessories for both technical and domestic installation should not be recessed into walls enclosing technical areas as this will reduce the effectiveness of the sound insulation of the walls. All conduits, fittings and accessories should be surface mounted on the structure although a flush appearance may often by achieved by the addition of an approved surface treatment.

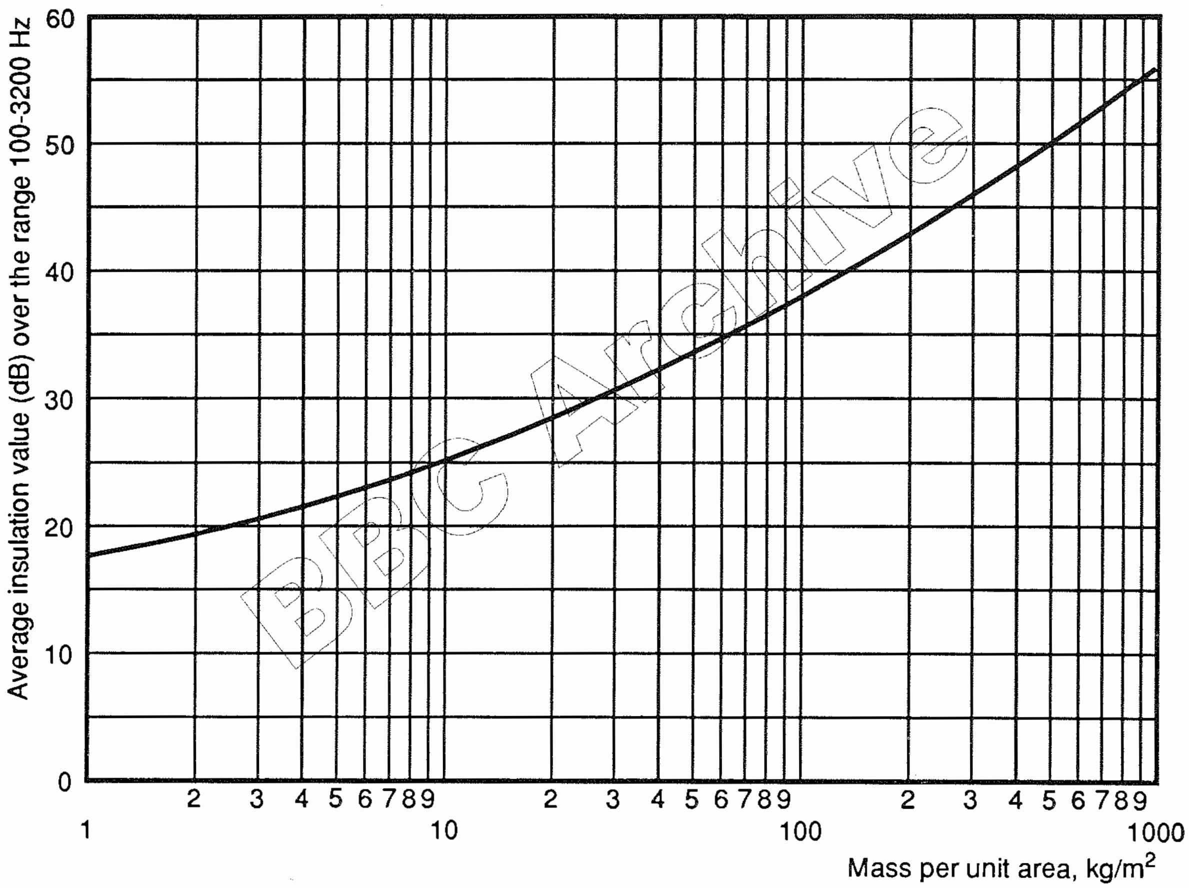


Figure 8 Sound Insulation. Mass Law Curve

Typical Comparison of Building Materials and their Approximate Density

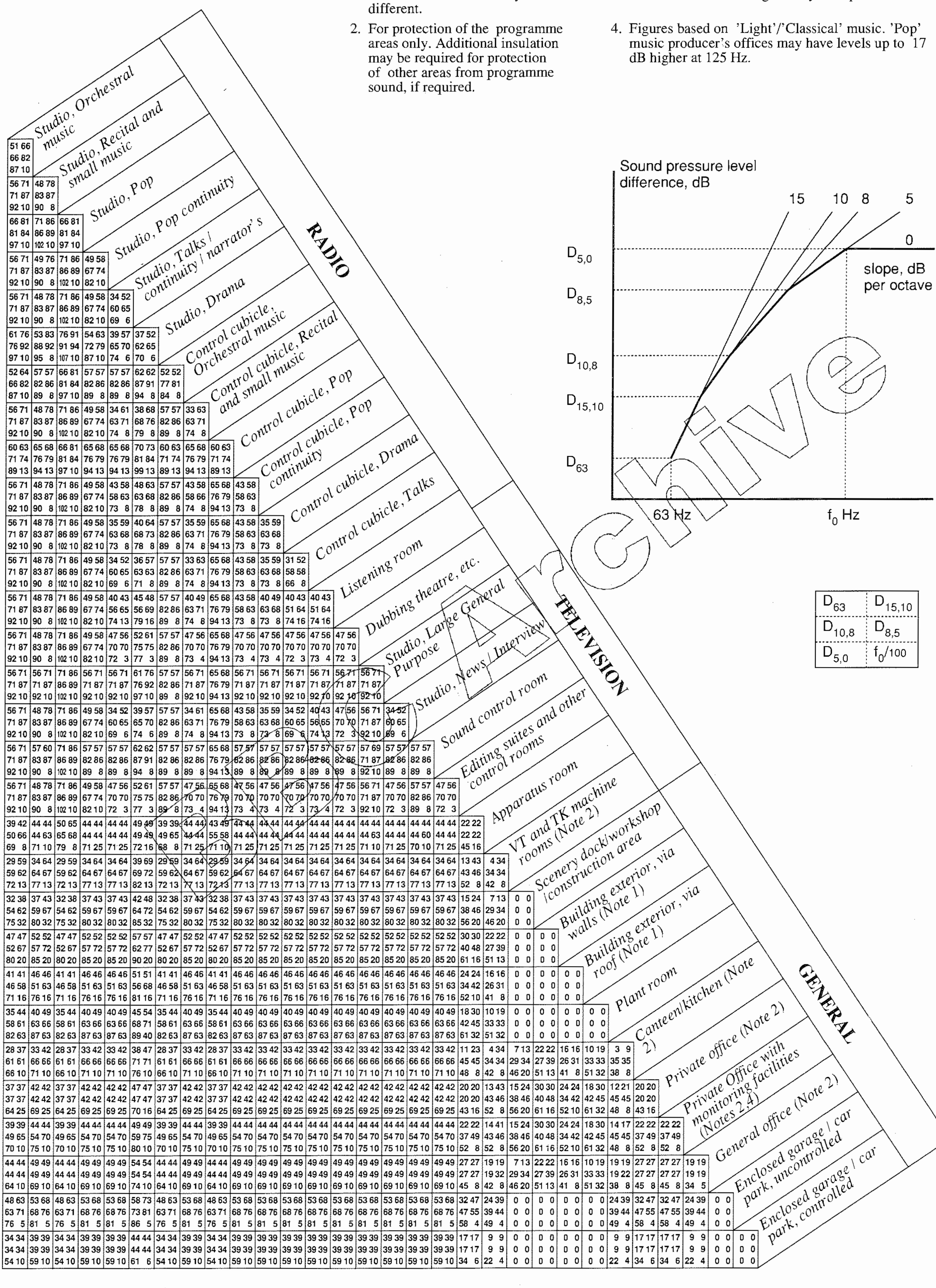
		kg/m² per mm thickness
(i)	Aluminium, flat sheet	2.8
(ii)	Asphalt flooring	1.95 - 2.34
(iii)	Asphalt roofing, 2 layers	2.23
(iv)	Blockboard, laminated	0.46
(v)	Blockwork, concrete cellular with ballast and stone aggregate	1.59
(vi)	Blockwork, concrete solid using stone aggregate	2.15
(vii)	Blockwork, hollow clay medium density	1.11
(viii)	Blockwork, Thermalite completed blockwork in standard or smooth faced blocks, unplastered	0.77
(ix)	Brickwork, Clay, solid, low density	2.0
(x)	Brickwork, Clay, solid, medium-density	2.15
(xi)	Brickwork, Clay, solid, high-density	2.33
(xii)	Chipboard	0.77
(xiii)	Concrete, natural aggregates 1: 2: 4 mix (2,307 kg/m³)	2.31
(xiv)	Concrete, lightweight aggregates normal (1121 kg/m³)	1.12
(xv)	Copper, flat sheet	8.86
(xvi)	Cork, normal board	0.17
(xvii)	Cork, flooring compressed	0.29
(xviii)	Fibreboard, insulation board	0.27
(xix)	Floor Units Hollow Clay Floor Blocks without ribs or concrete topping but including reinforcement and mortar jointing between blocks	1.27 - 1.44
	Hollow Concrete Floor Units including any concrete topping necessary for constructional purposes	1.39 - 1.68
(xx)	Glass, clear plate	2.56
(xxi)	Hardboard	1.06
(xxii)	Lead, sheet	11.40
(xxiii)	Plaster, gypsum 2-coat	1.73
(xxiv)	Plasterboard, solid core gypsum	0.88
(xxv)	Plywood	0.6
(xxvi)	Reinforced concrete	2.4
(xxvii)	Sand	1.52 - 1.68
(xxviii)	Screeding 1:3 mix	2.3
(xxix)	Steel, mild steel sheet	7.72
(xxx)	Timber Softwood e.g. pine, spruce, Douglas fir	0.45 - 0.59
	Hardwood e.g. Burma teak, oak, maple	0.11 - 1.25
(xxxi)	Water	1.0
(xxxii)	Wood Floor, hardwood strip	0.73
(xxxiii)	Woodwool Slabs, width 600mm	0.51
(xxxiv)	Woodwool Slabs, channel reinforced, 600mm width	0.56

Figure 9

SOUND INSULATION CRITERIA

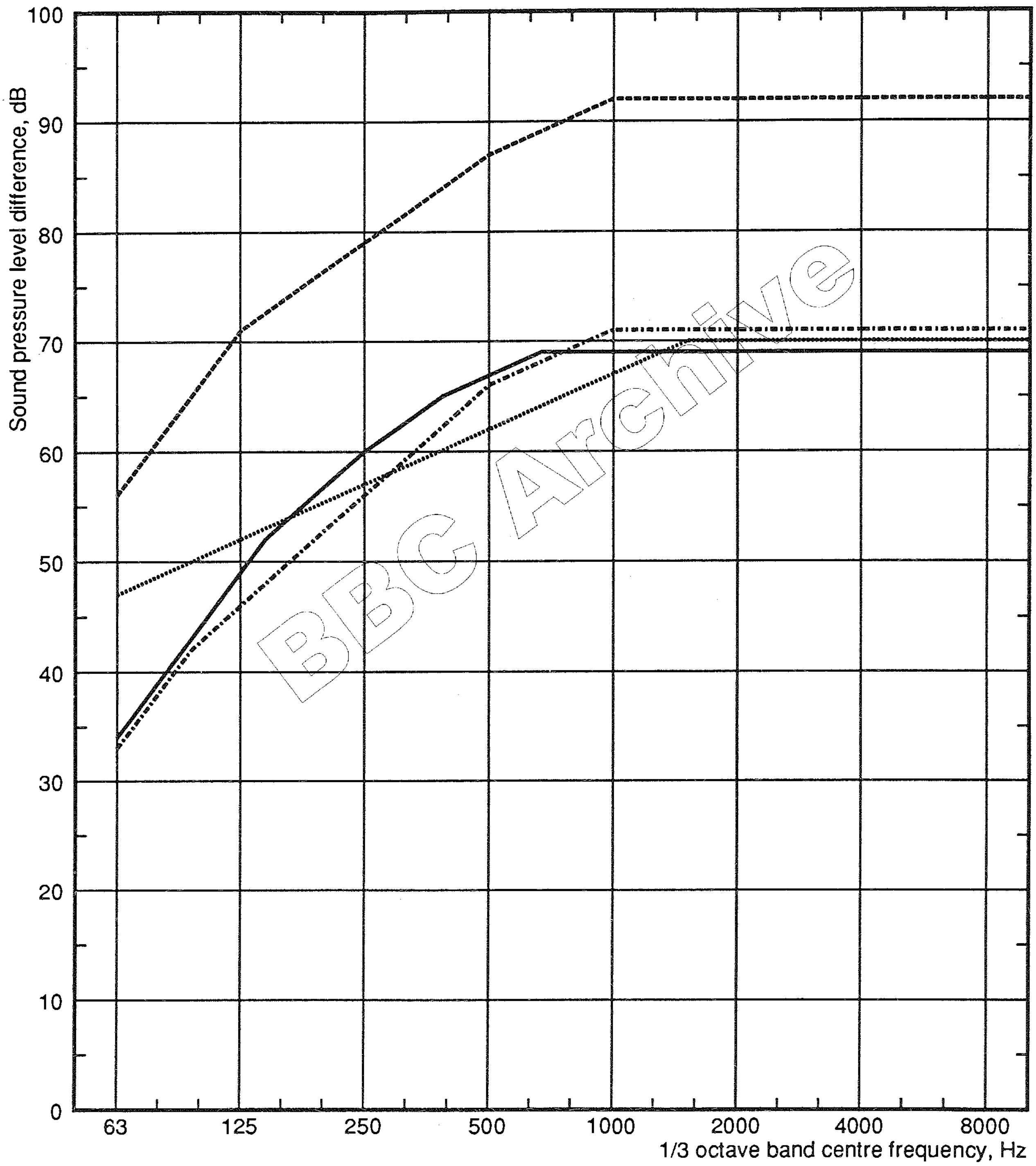
NOTES

1. For protection of the internal area from external sound. The requirements for areas needing exterior noise control may be different.
2. For protection of the programme areas only. Additional insulation may be required for protection of other areas from programme sound, if required.
3. The figures given are for complete protection. In most cases, 5dB may be subtracted from the specified insulations to give conditions which have been found to be generally acceptable.
4. Figures based on 'Light'/'Classical' music. 'Pop' music producer's offices may have levels up to 17 dB higher at 125 Hz.



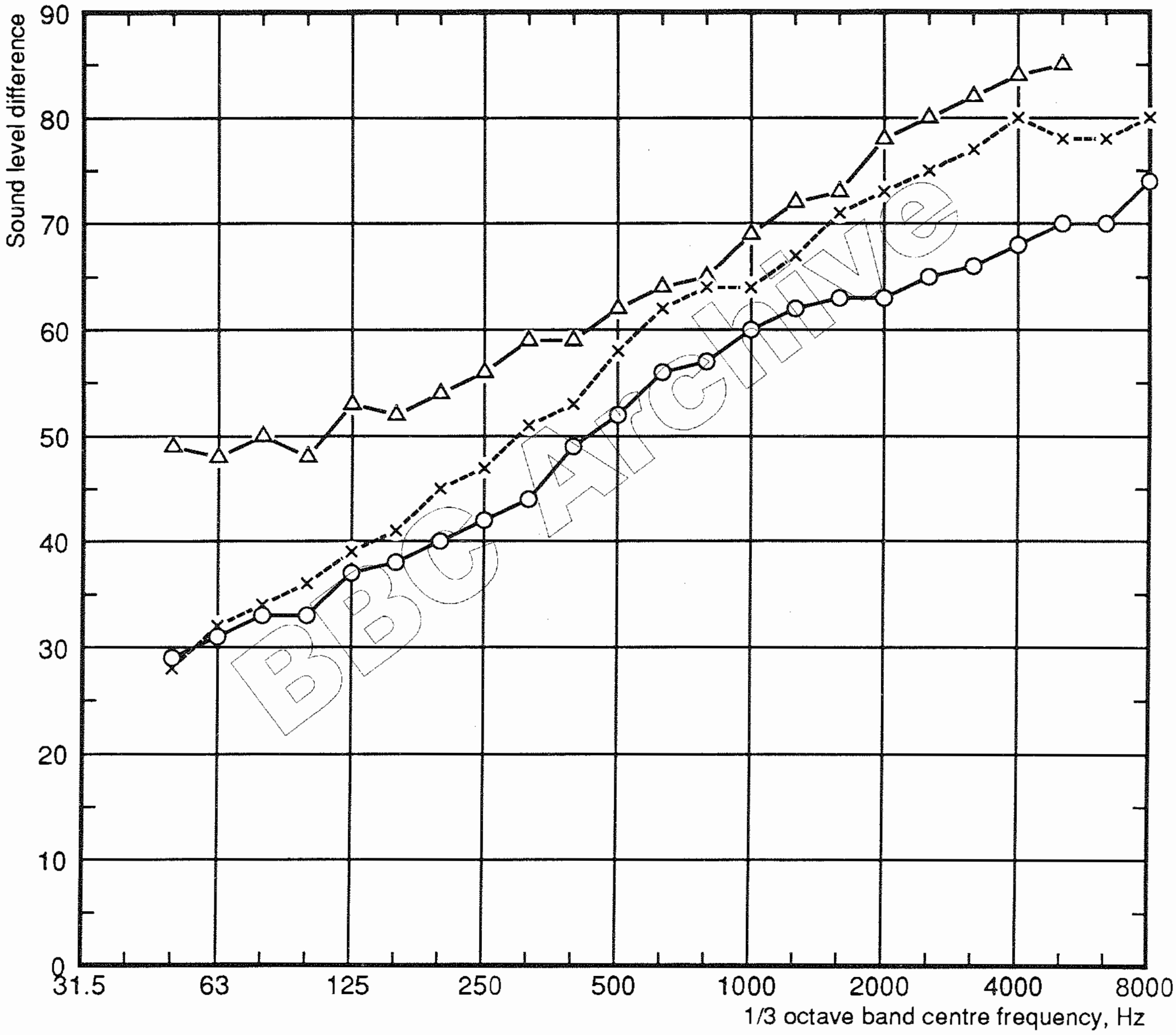
D_{63}	$D_{15,10}$
$D_{10,8}$	$D_{8,5}$
$D_{5,0}$	$f_0/100$

(For an enlargement of this diagram see pull out on Page 145).



(a) between two Radio talks studios
(b) between two large, general-purpose Television studios
(c) between a Radio drama studio and a private office
(d) between a Television sound control room and a canteen/kitchen

Figure 11 Sound Insulation Criteria. Worked examples



O———O Double leaf, 112mm brick, 50mm cavity, rigid wall ties(15 samples)

x-------x as above but with flexible wall ties, (22 samples)

Δ———Δ Triple leaf, 112-225-112 mm with 50 mm cavities (1 sample)

Figure 12 Typical examples of airborne sound pressure level differences for brick walls

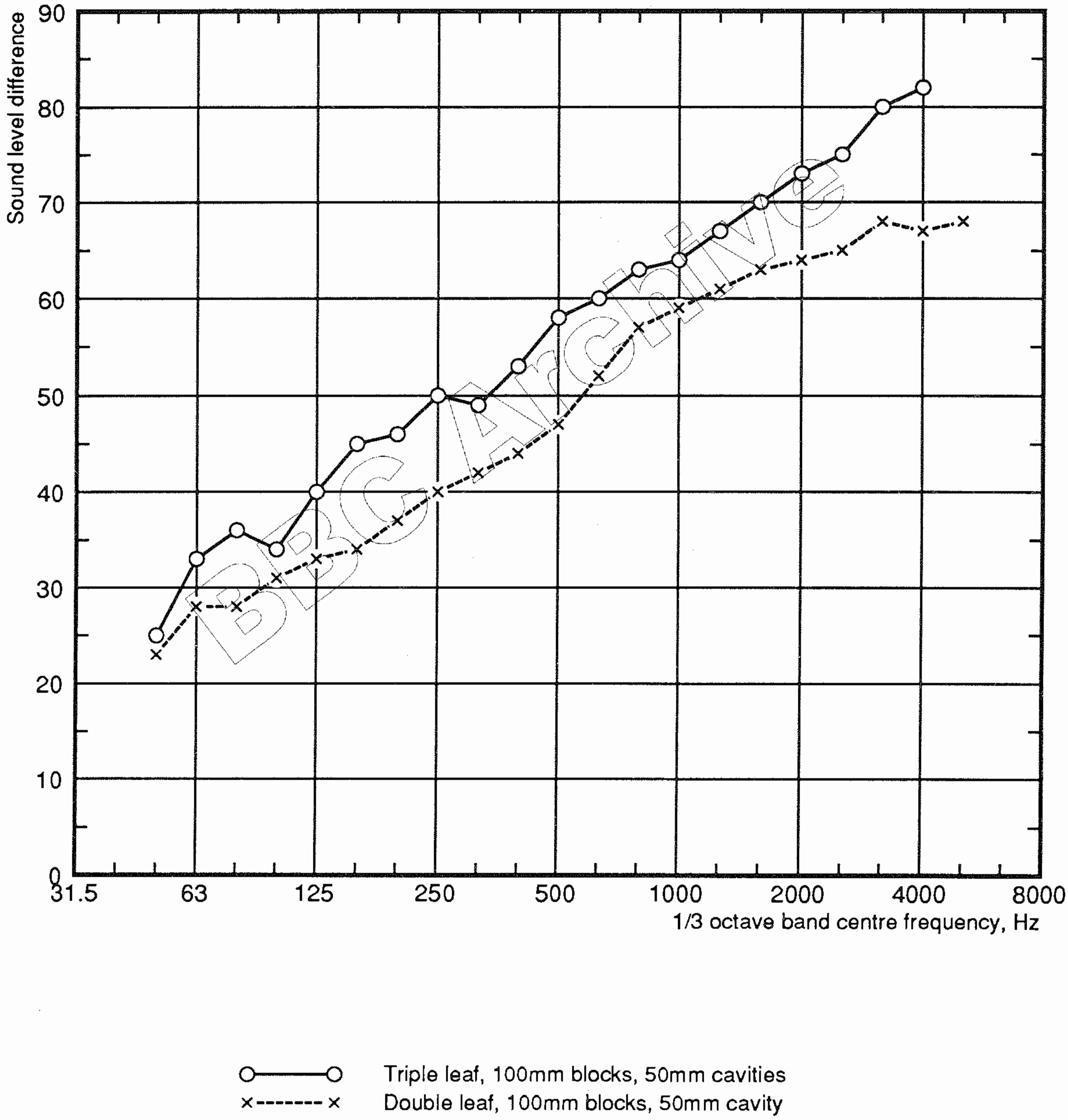


Figure 13 Typical examples of airborne sound pressure level differences for blockwork walls

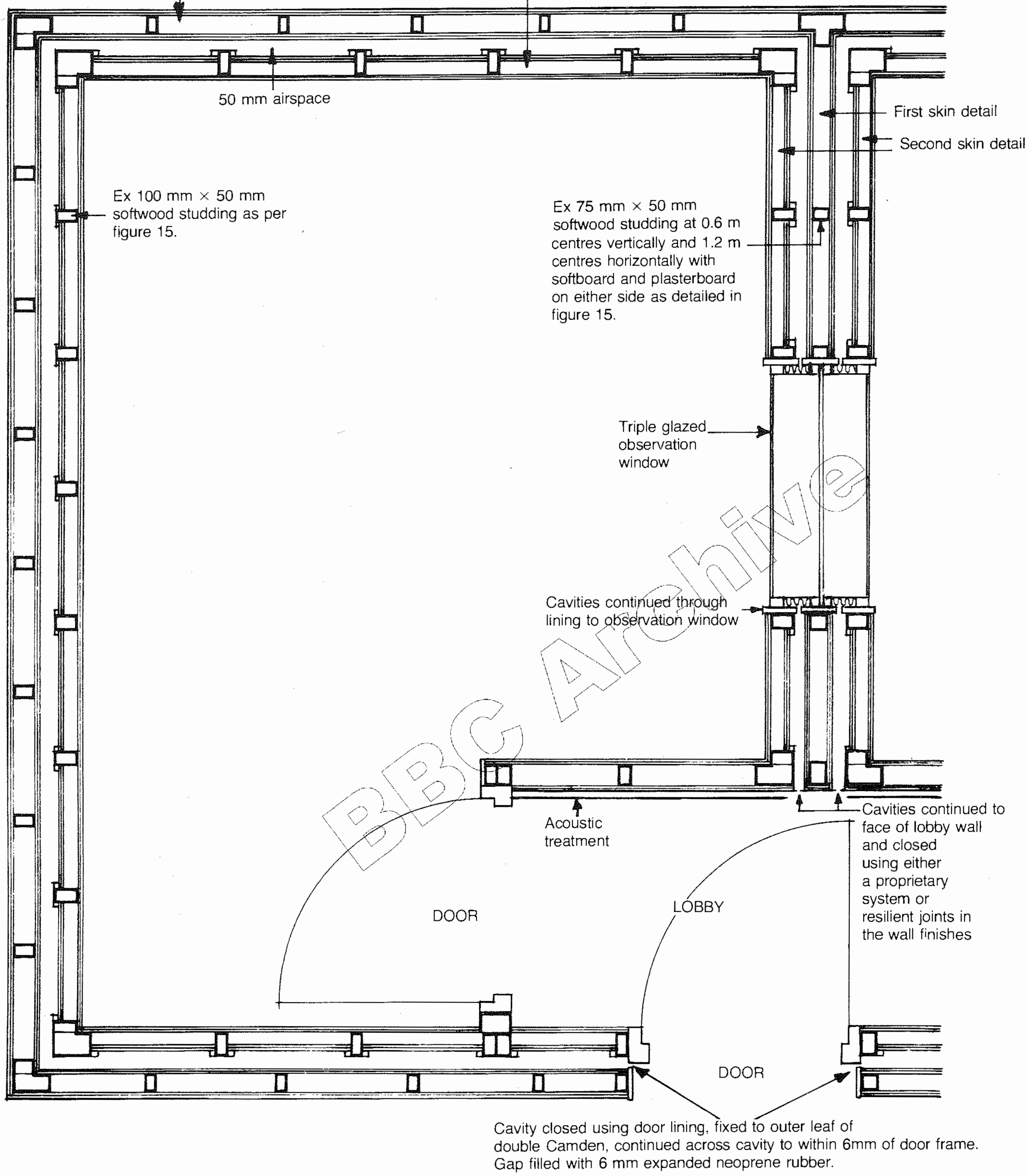


Figure 14 Plan showing typical details of studio construction using single, double, and triple Camden partitions

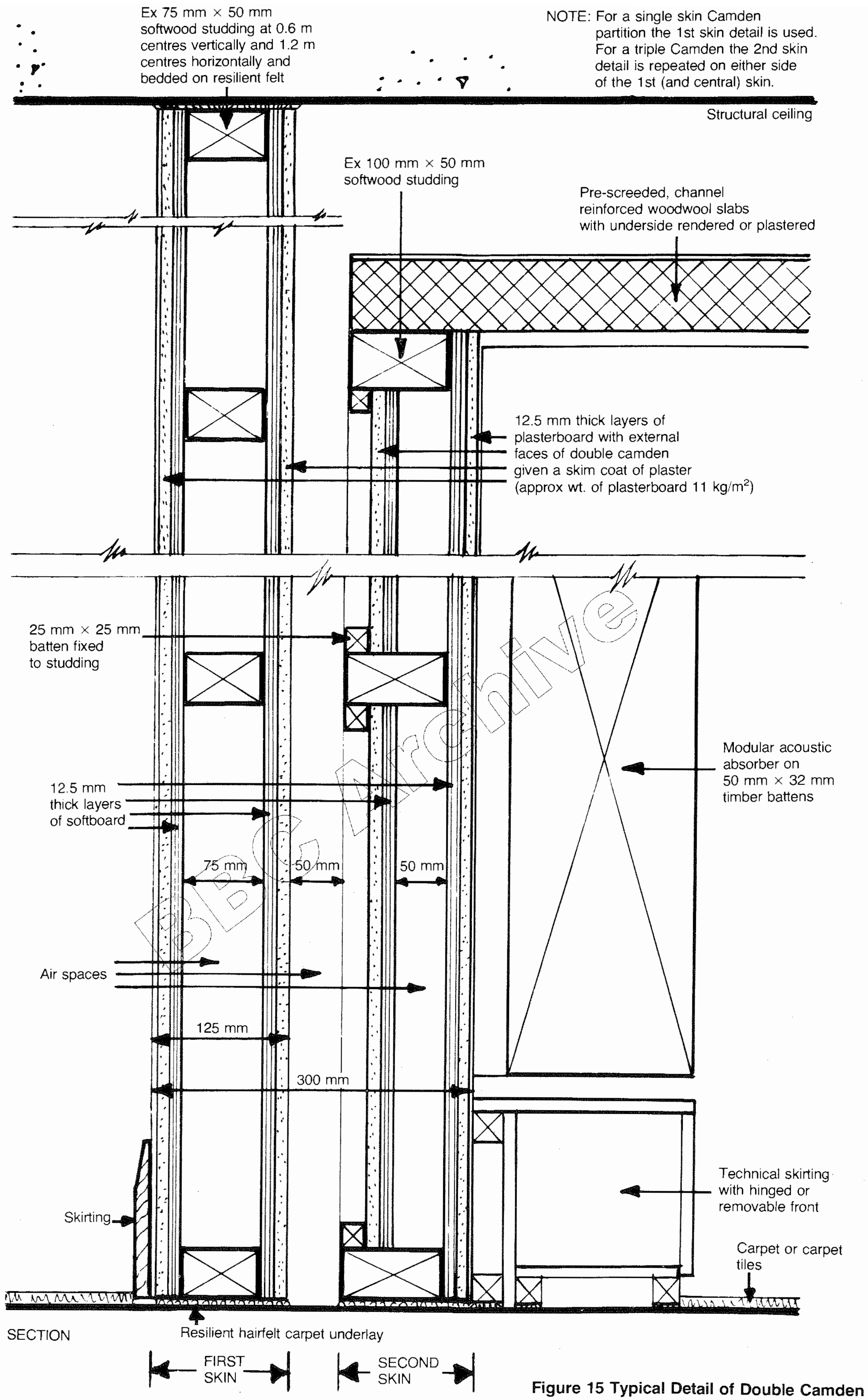


Figure 15 Typical Detail of Double Camden

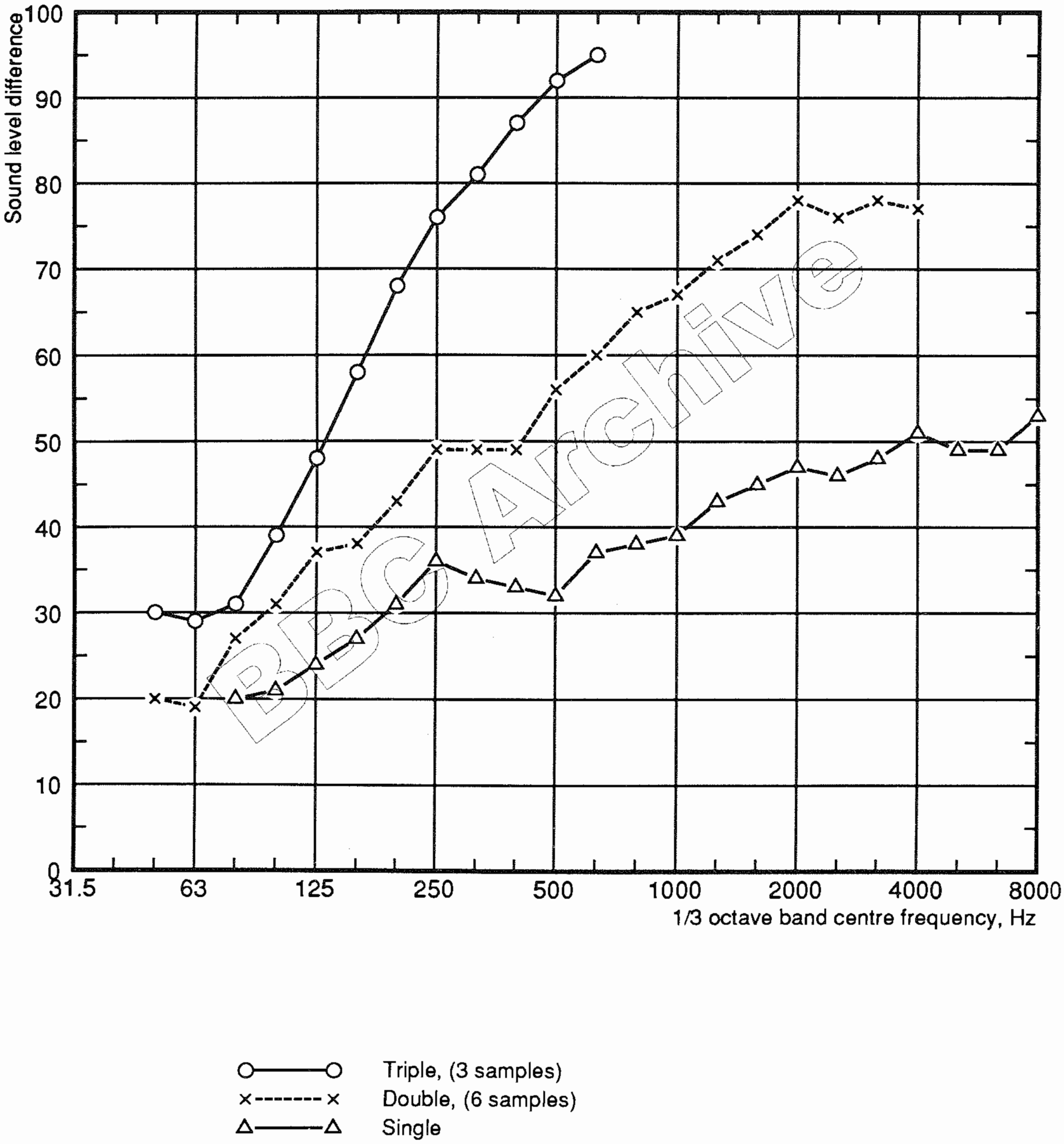


Figure 16 Typical examples of airborne sound pressure level differences for Camden partitions

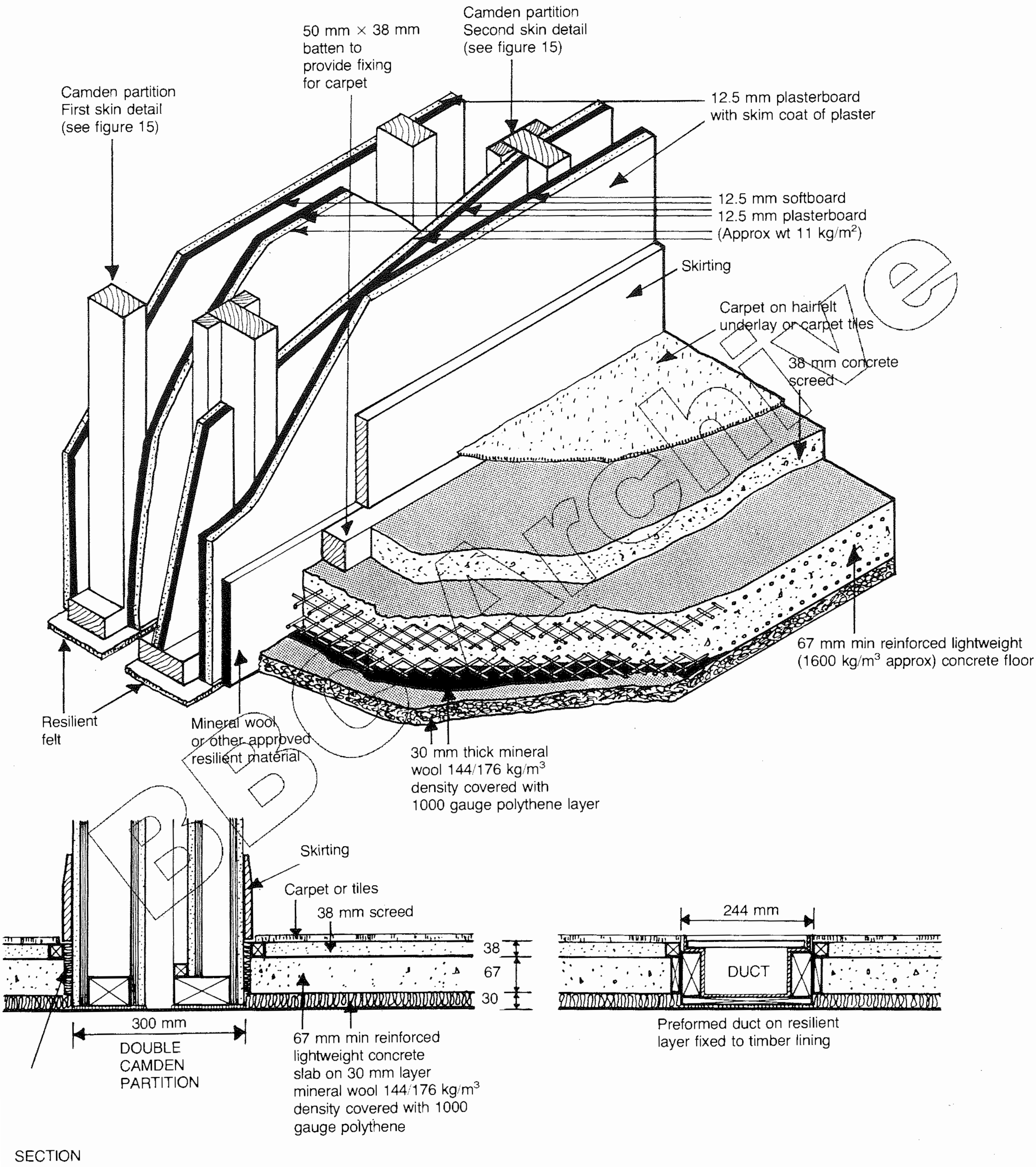


Figure 17 Typical Section through a Lightweight Concrete Floating Floor

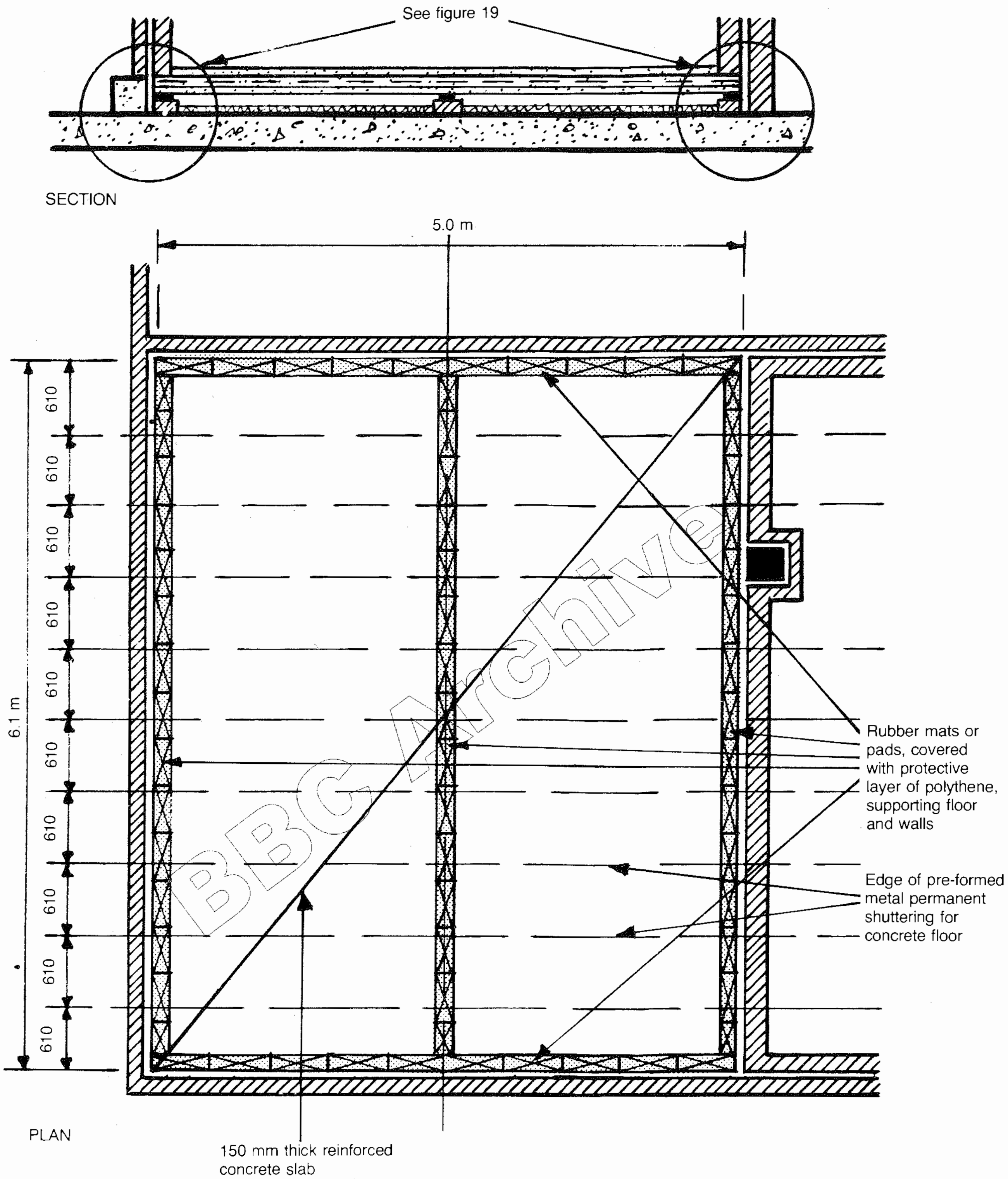
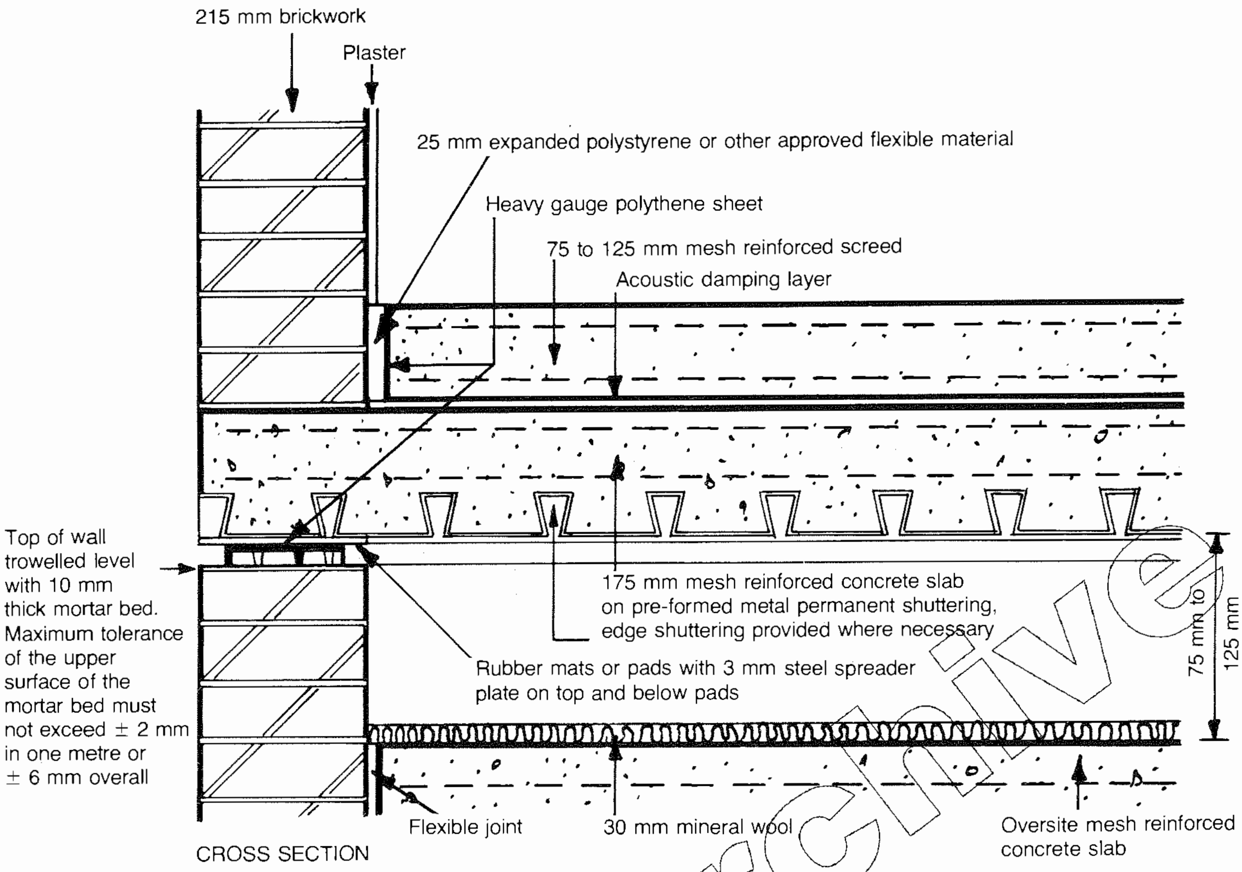


Figure 18 Plan and Section showing typical layout of rubber mats or pads under a floated concrete floor with the walls and ceiling supported off the floated floor



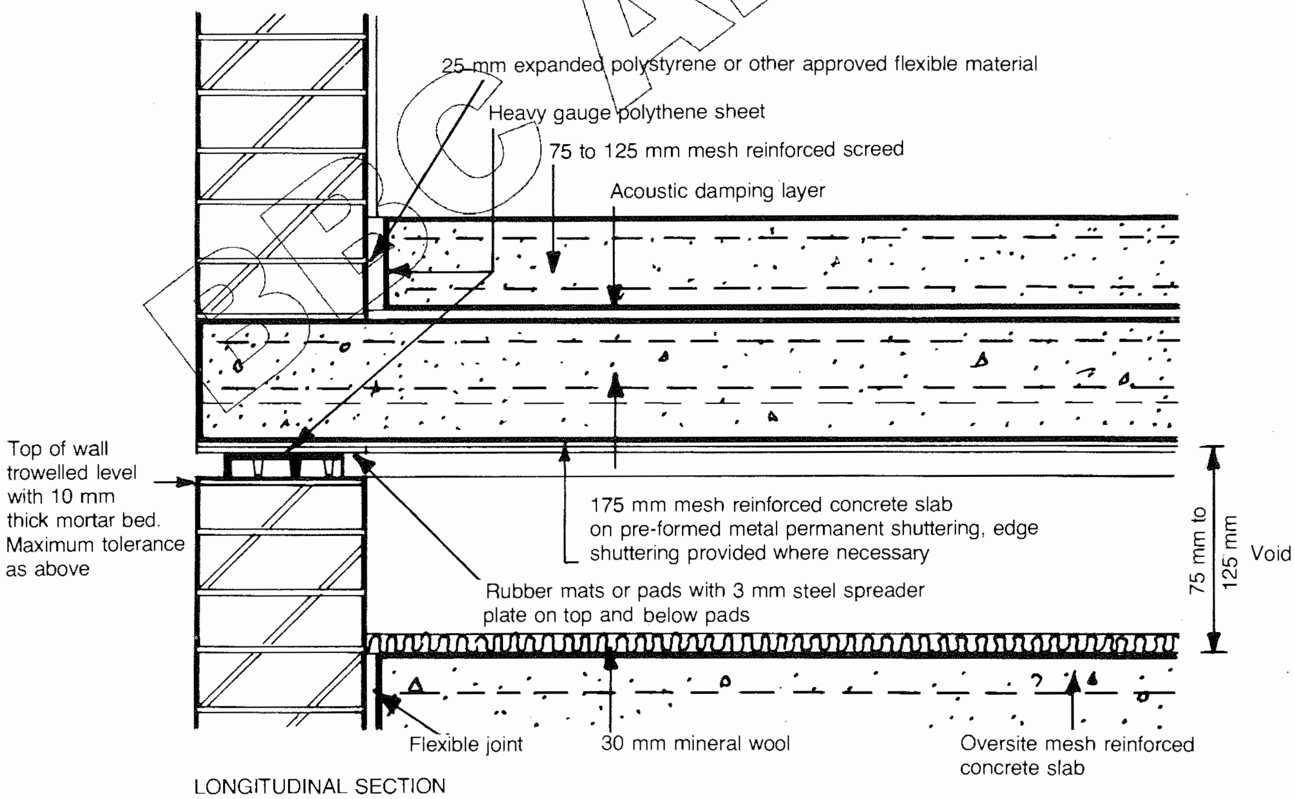
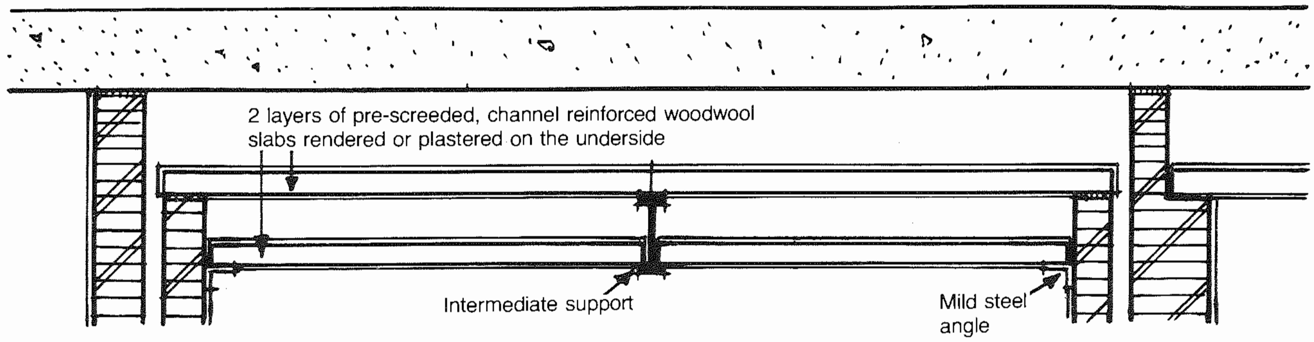
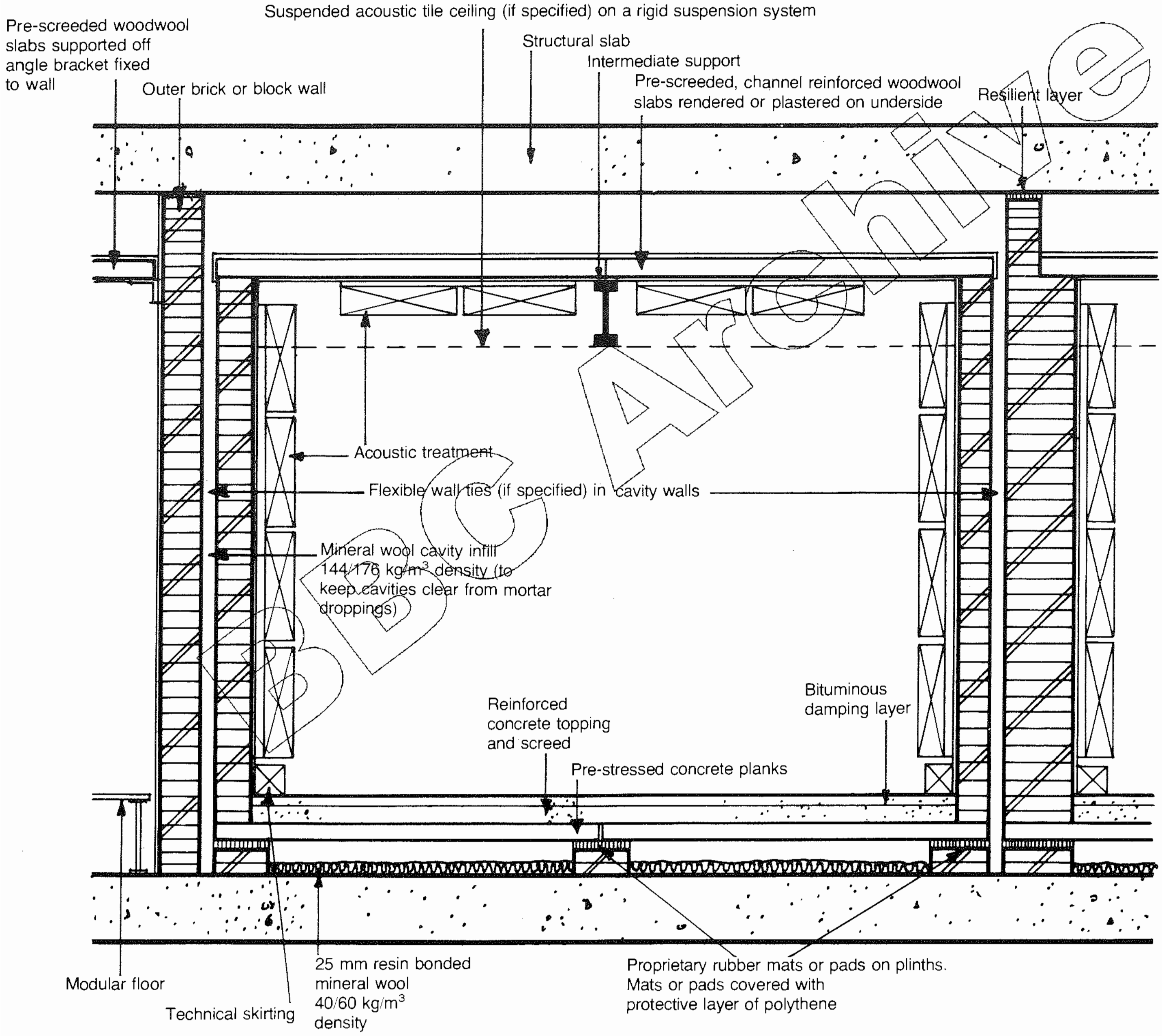


Figure 19 Sections through a typical floated floor using metal sheeting as permanent shuttering



SECTION showing typical double woodwool construction over box within a box structures



SECTION

Figure 20 Diagrammatic sections showing typical box within a box floated structure using pre-stressed concrete planks as permanent shuttering

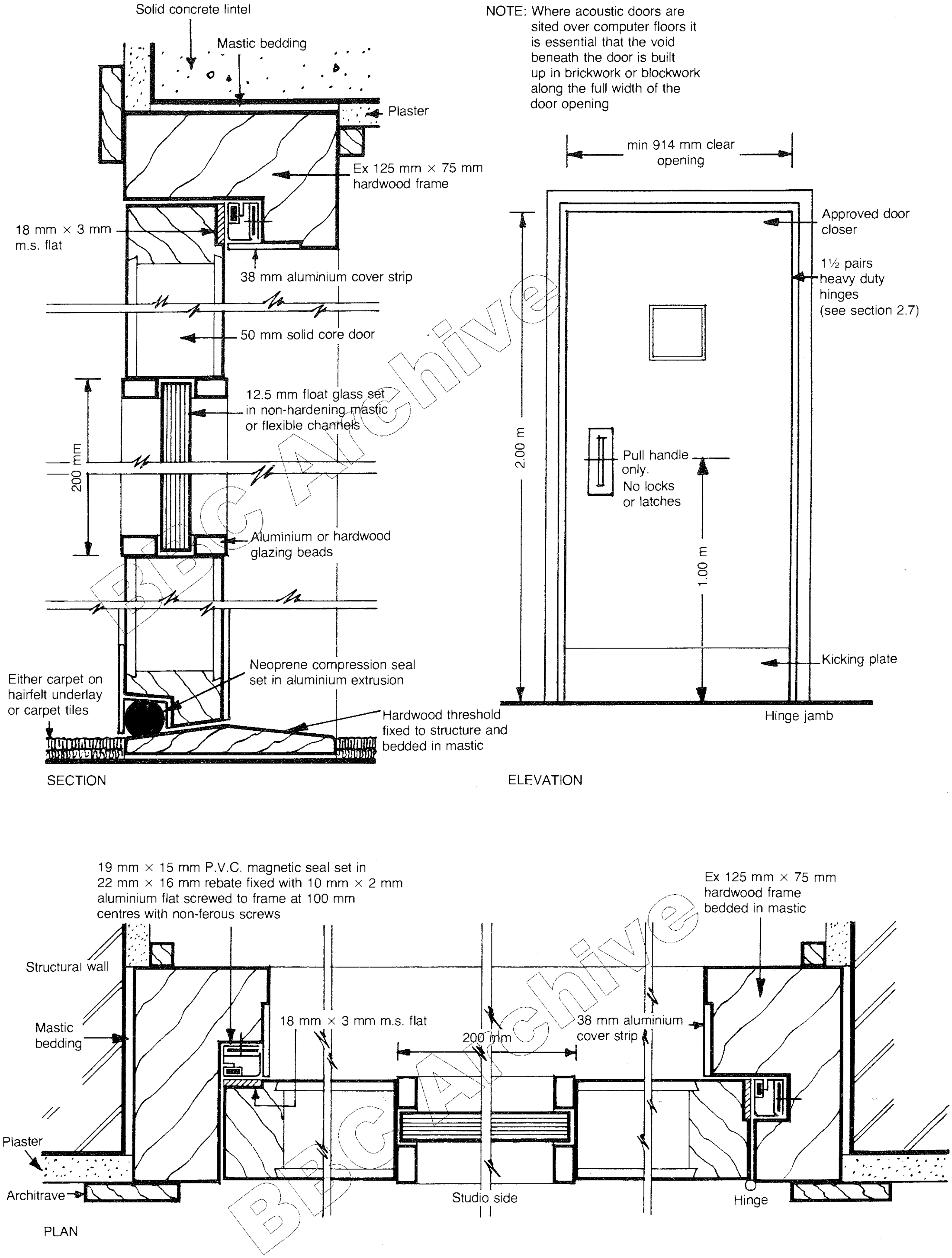


Figure 21 Typical acoustic personnel door. Solid cored

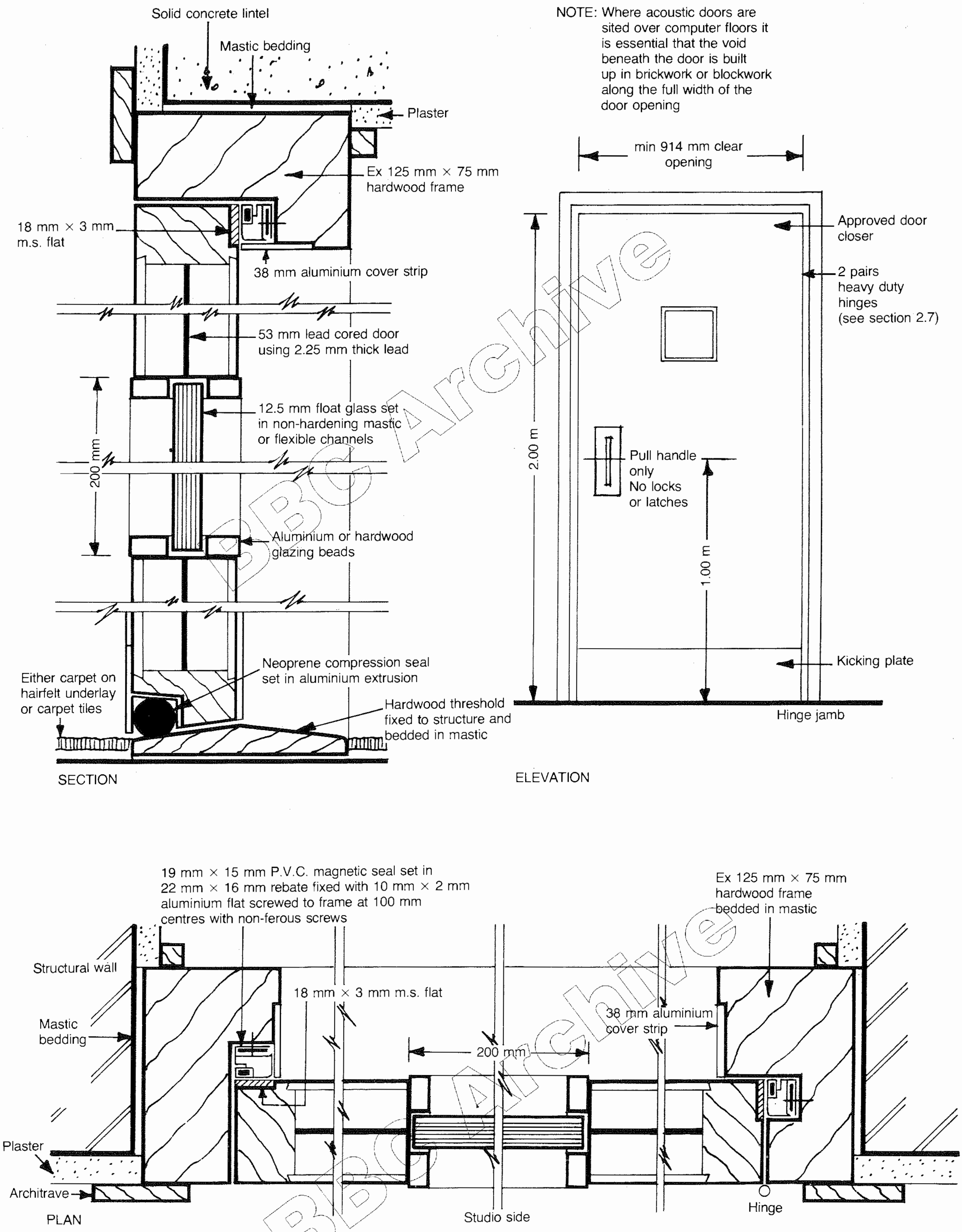
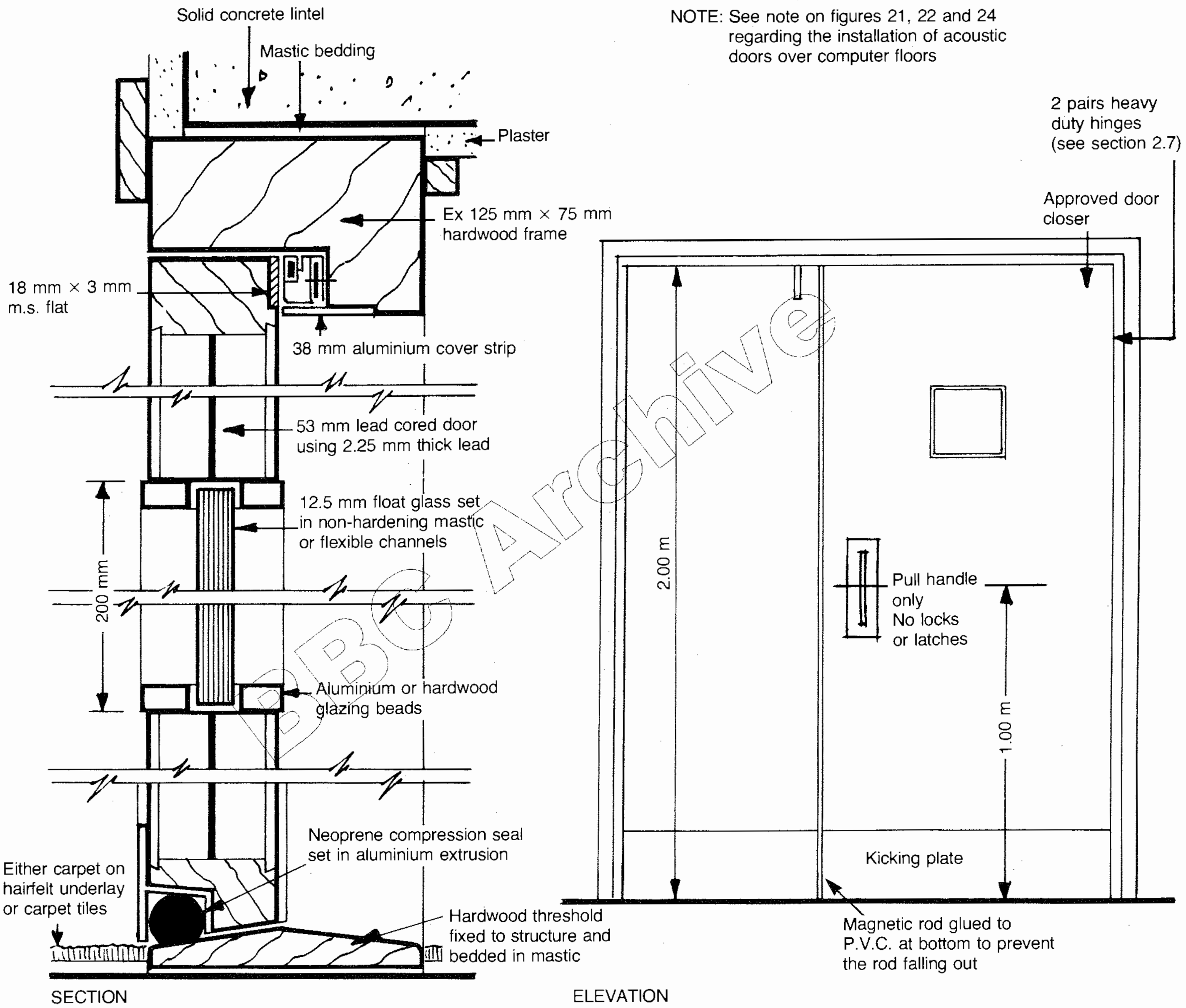


Figure 22 Typical acoustic personnel door. Lead cored



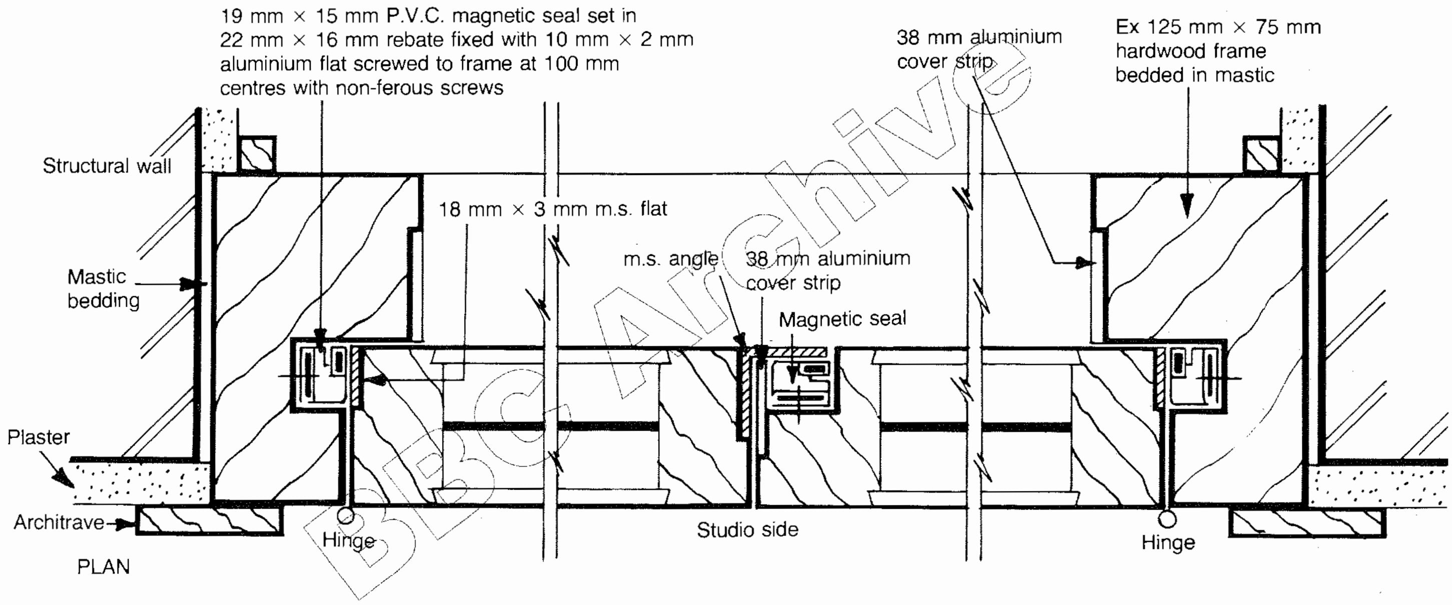


Figure 23 Typical double acoustic personnel door. Lead cored

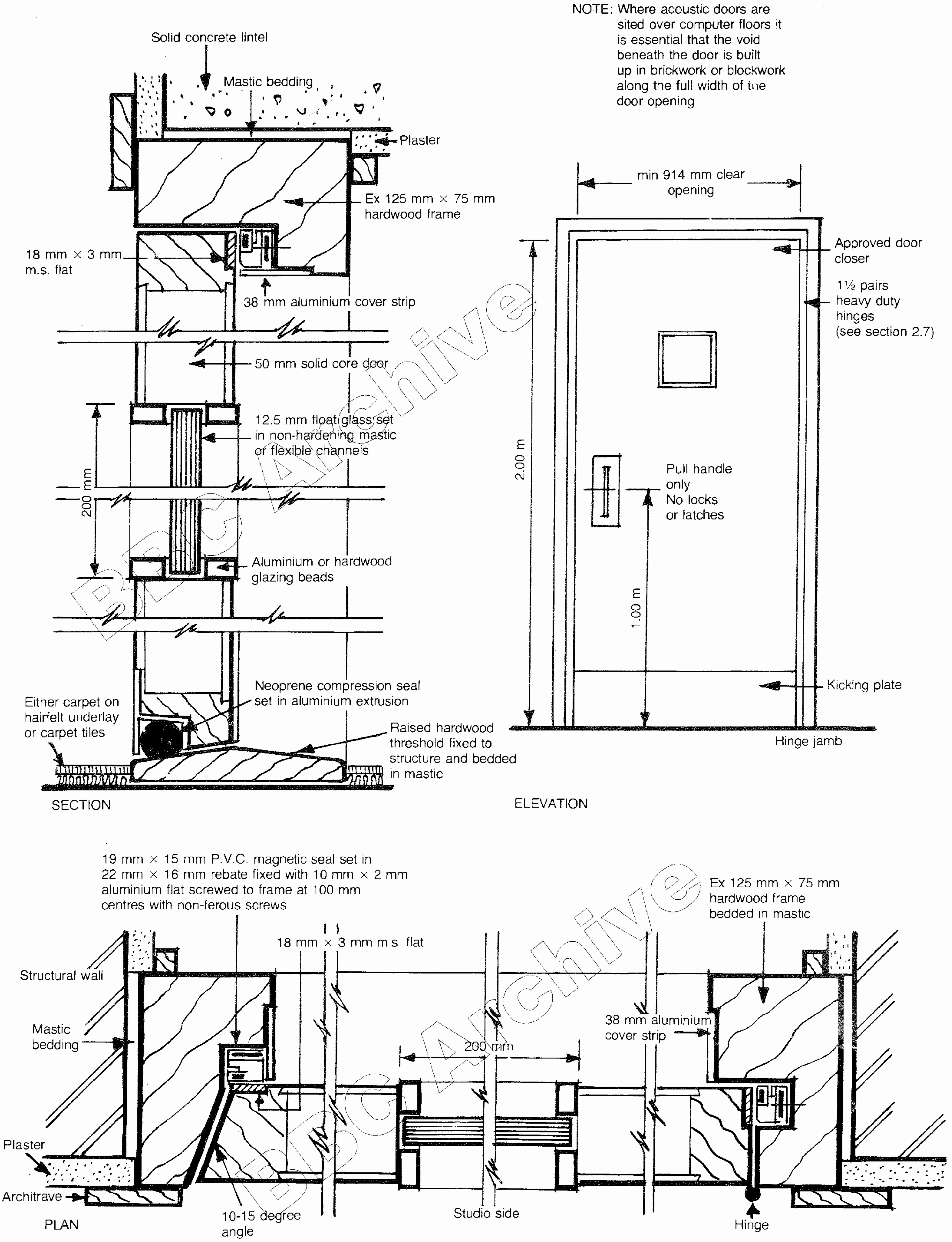


Figure 24 Typical acoustic personnel door illustrating angled leading edge and amended threshold

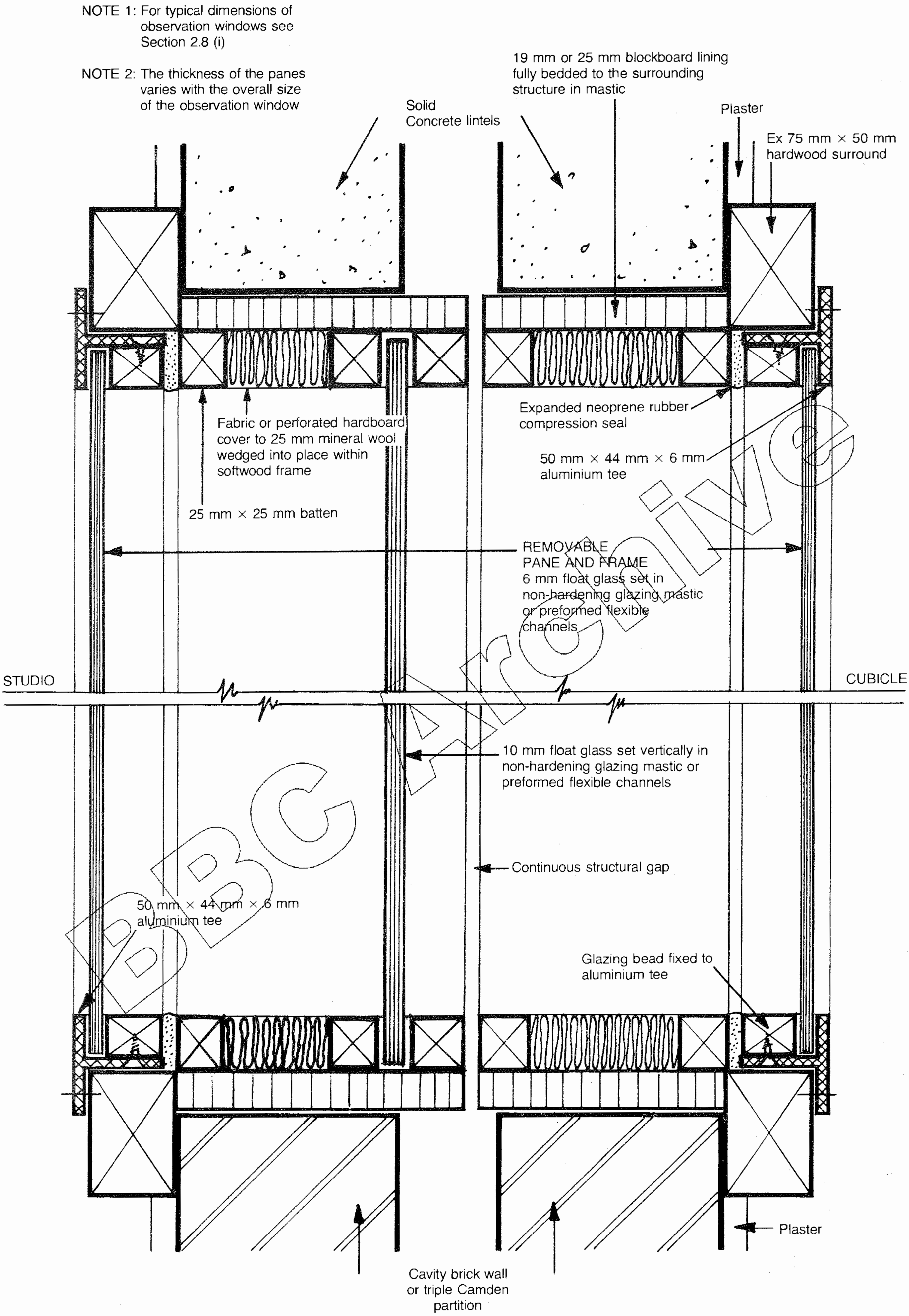


Figure 25 Section showing typical detail of a triple glazed observation window

NOTE 1: For typical dimensions of observation windows see Section 2.8 (i)

NOTE 2: The thickness of panes varies with the overall size of the observation window

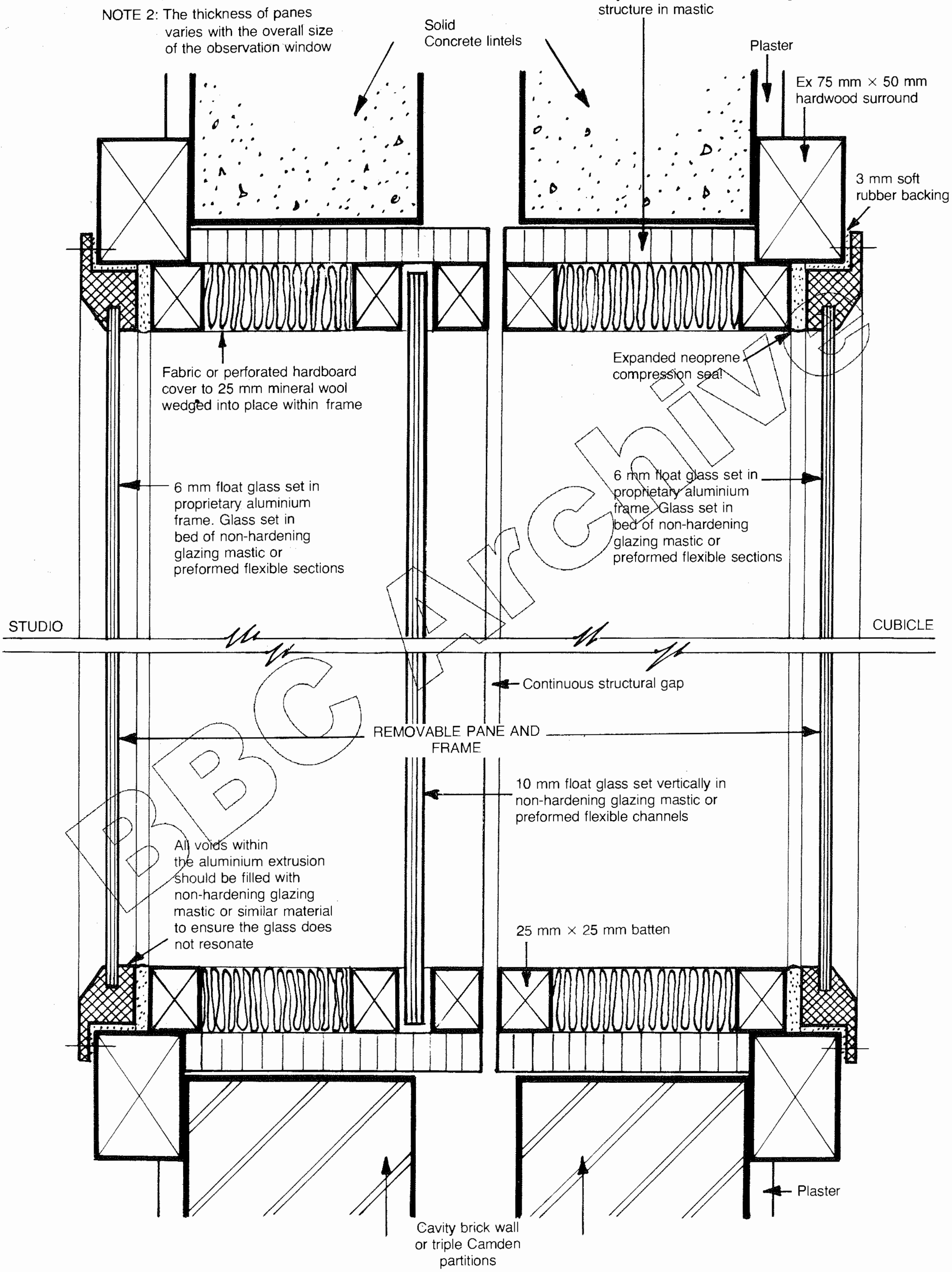


Figure 26 Section showing typical triple glazed observation window using proprietary aluminium frames

NOTE 1: For typical dimensions of observation windows see Section 2.8 (i)

NOTE 2: The thickness of the panes varies with the overall size of the observation window

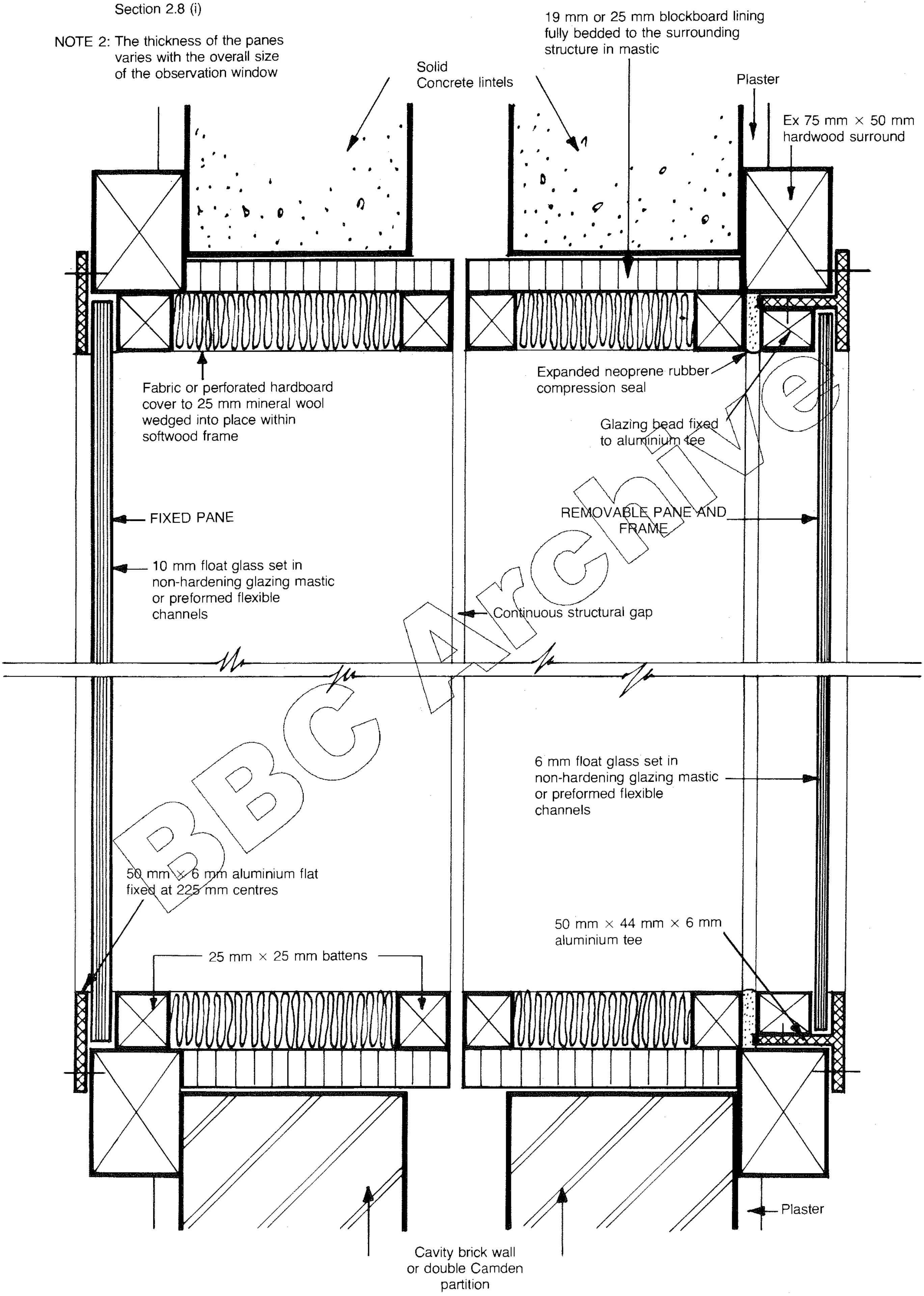


Figure 27 Section showing typical double glazed observation window

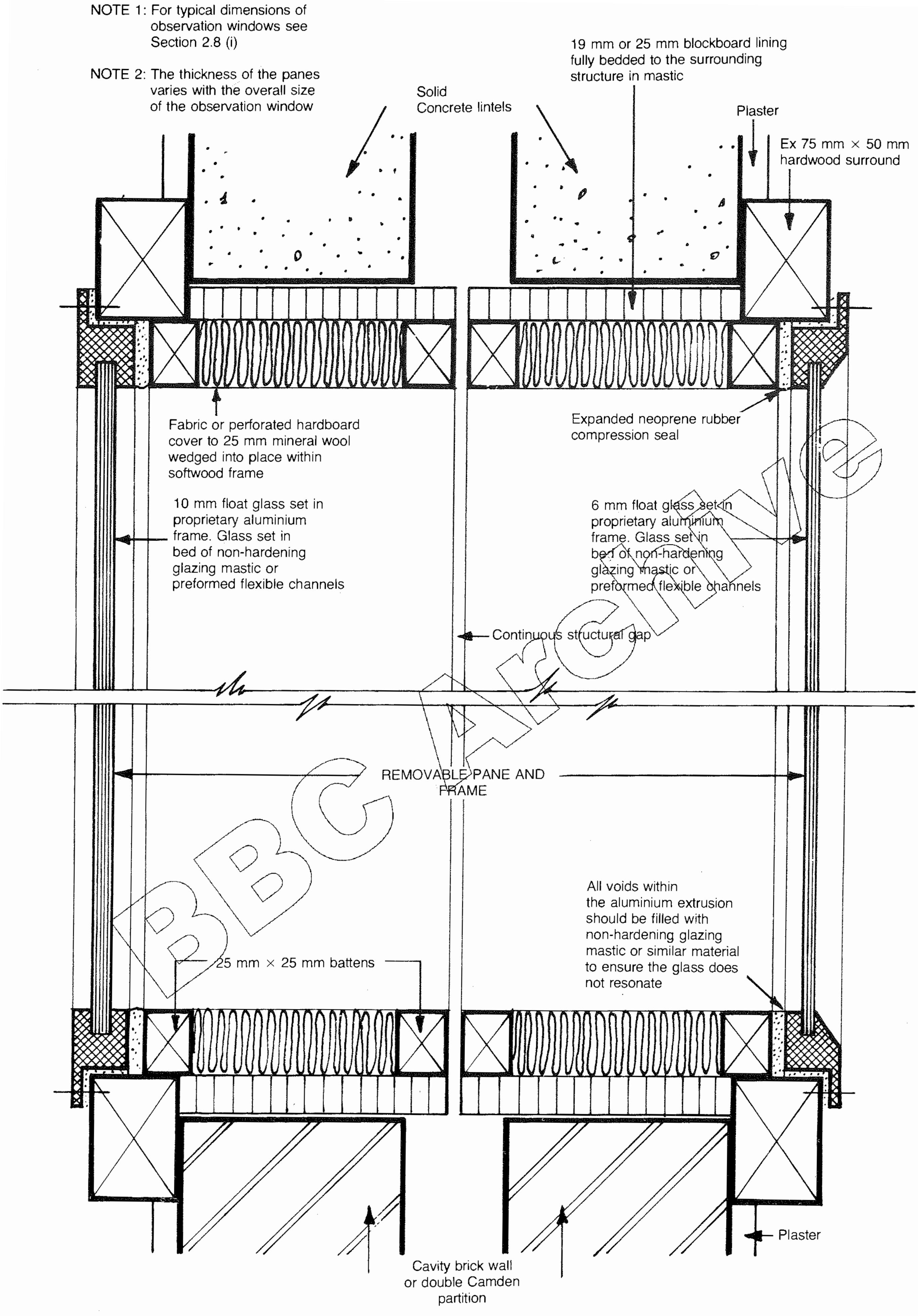


Figure 28 Section showing typical double glazed observation window using proprietary aluminium frames

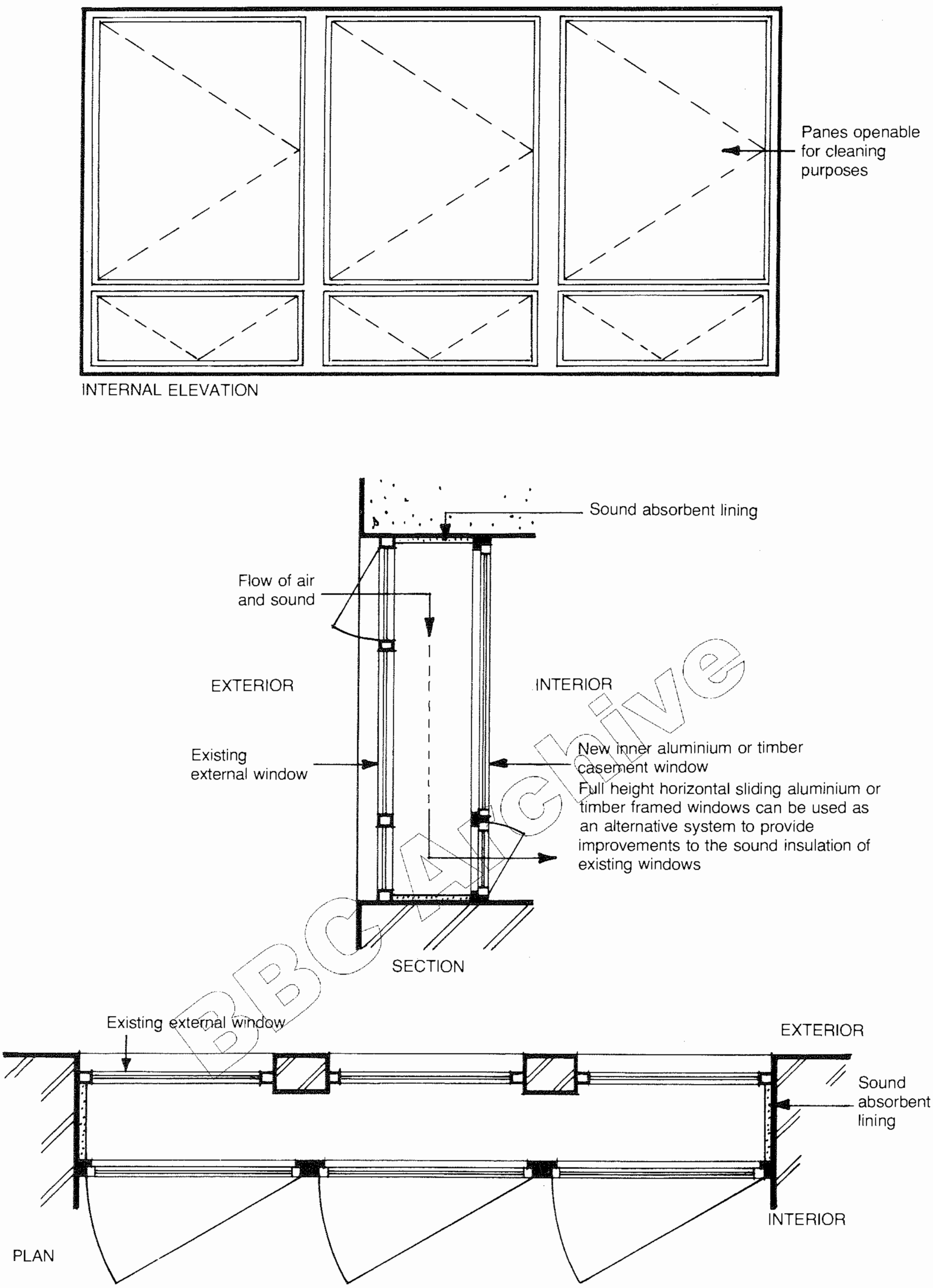
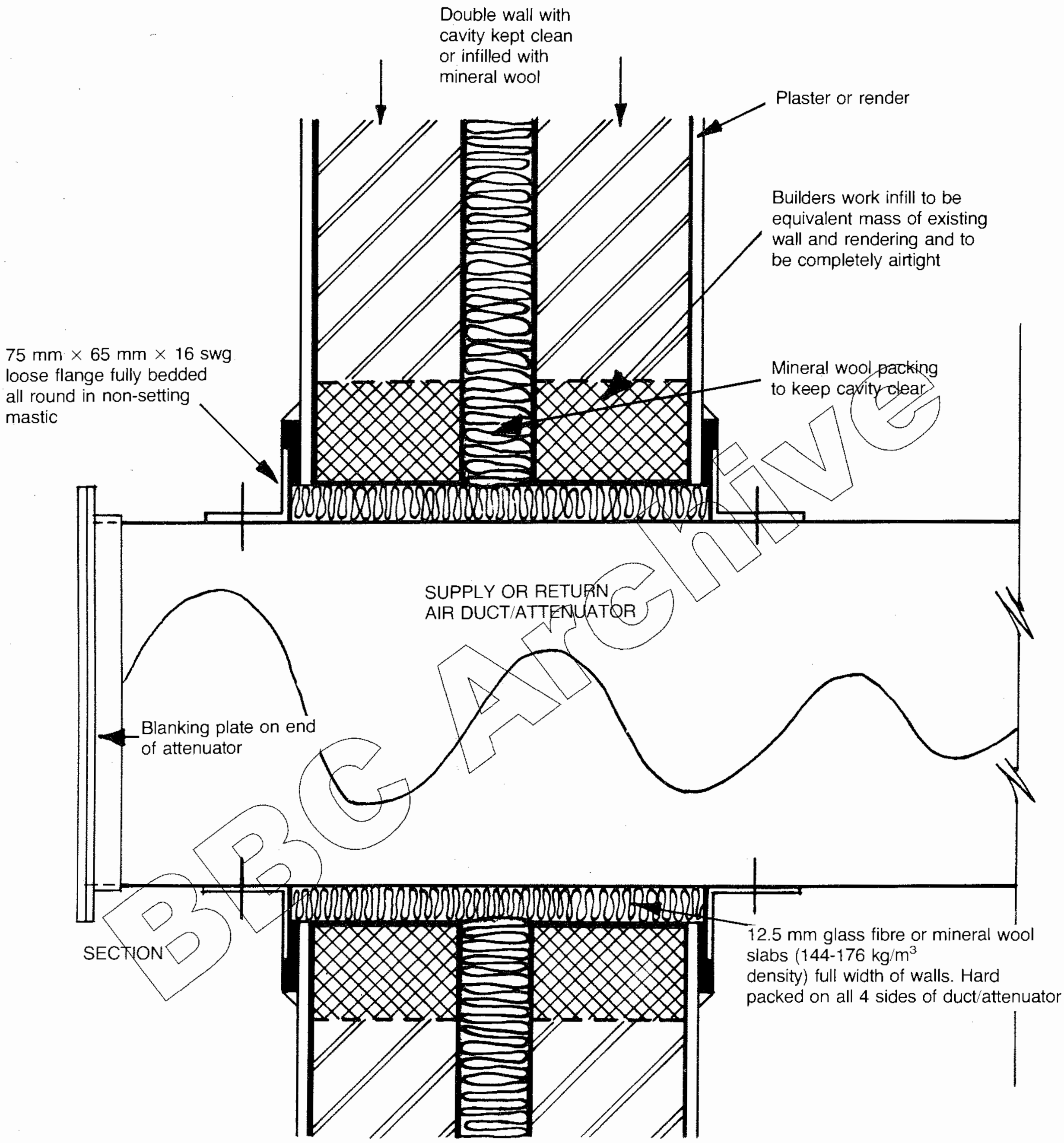


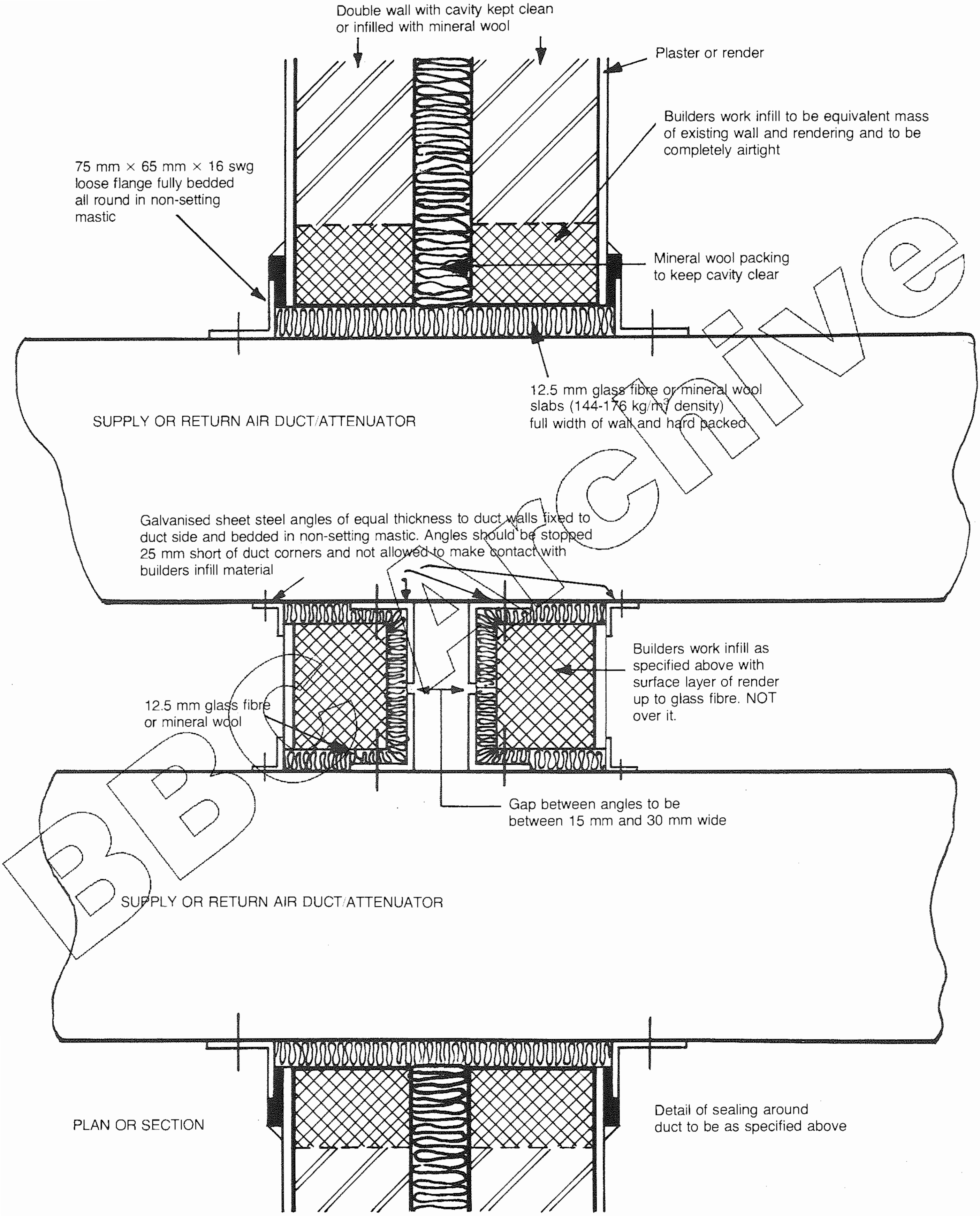
Figure 29 Typical detail showing secondary external double glazing for offices



ORDER OF ASSEMBLY

1. Cut hole in wall and insert cavity infill.
2. Erect ductwork.
3. Form glass fibre or mineral wool sleeve over the duct/attenuator. Secured by wire ties to duct casing if necessary.
4. Fill gap between wall and glass fibre both sides of cavity wall with builders work infill of equivalent mass to wall. A good seal between glass fibre sleeve and infill and between infill and wall is essential.
5. Render up to edge of glass fibre sleeve.
6. Fit loose flanges, fully bedded in non-setting mastic, to duct.

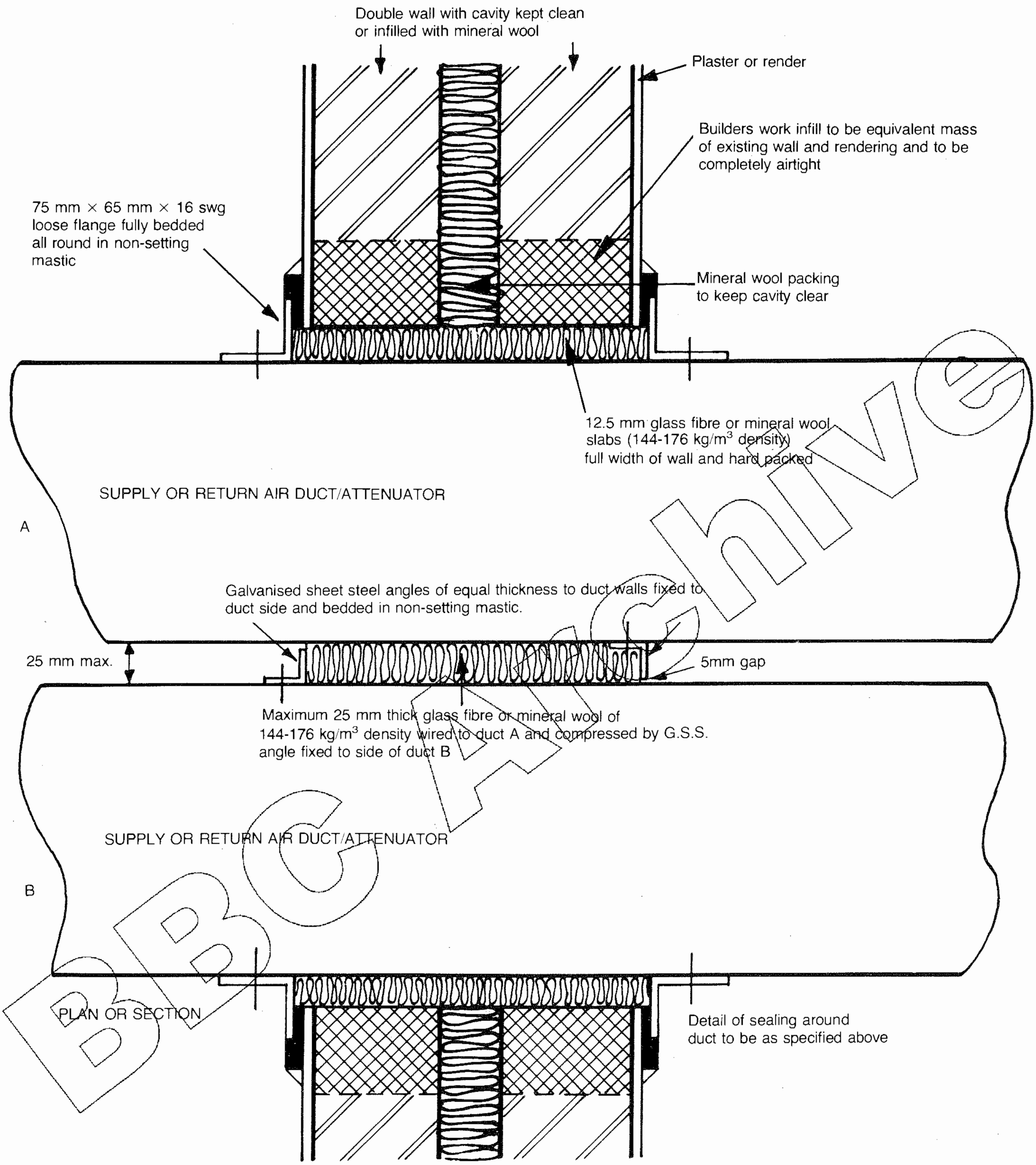
Figure 30 Typical detail for sealing around ventilation ducts where they pass through building structures



ORDER OF ASSEMBLY

1. Cut hole in wall and insert cavity infill.
2. Erect ductwork and fit G.S.S. angles, sealing mating surfaces with mastic.
3. Form glass fibre sleeves over ducts secured by wire ties if necessary and fit glass fibre slab against angles ensuring good overlap past end of angles.
4. Fill gaps between ducts and also between ducts and wall with builders work infill as specified above.
5. Render up to edges of glass fibre sleeves.
6. Fit loose flanges, fully bedded in non-setting mastic, to ducts.

Figure 31 Typical detail for sealing around ventilation ducts where they pass through building structures



ORDER OF ASSEMBLY

1. Cut hole in wall and insert cavity infill.
2. Erect duct A with glass fibre or mineral wool slab wired to duct and retained by G.S.S. angle.
3. Fit duct B in position with the G.S.S angle fixed to side of duct compressing the glass fibre or mineral wool slab between the ducts.
   The G.S.S. angles must in no way make contact with the duct other than the one it is fixed to.
4. Fill gap between wall and outer layer of glass fibre with builders work infill of equivalent mass to wall. A good seal between glass fibre sleeve and infill and between infill and wall is essential.
5. Render up to edge of glass fibre sleeve.
6. Fit loose flanges, fully bedded in non-setting mastic, to ducts.

Figure 32 Typical detail for sealing around ventilation ducts where they pass through building structures

NOTE 1: Direct routes through walls separating technical areas for cable routes must be avoided wherever possible.

NOTE 2: The principles shown in this plan by arrowed routes apply to routes for ALL forms of electrical services and ventilation ductwork runs.

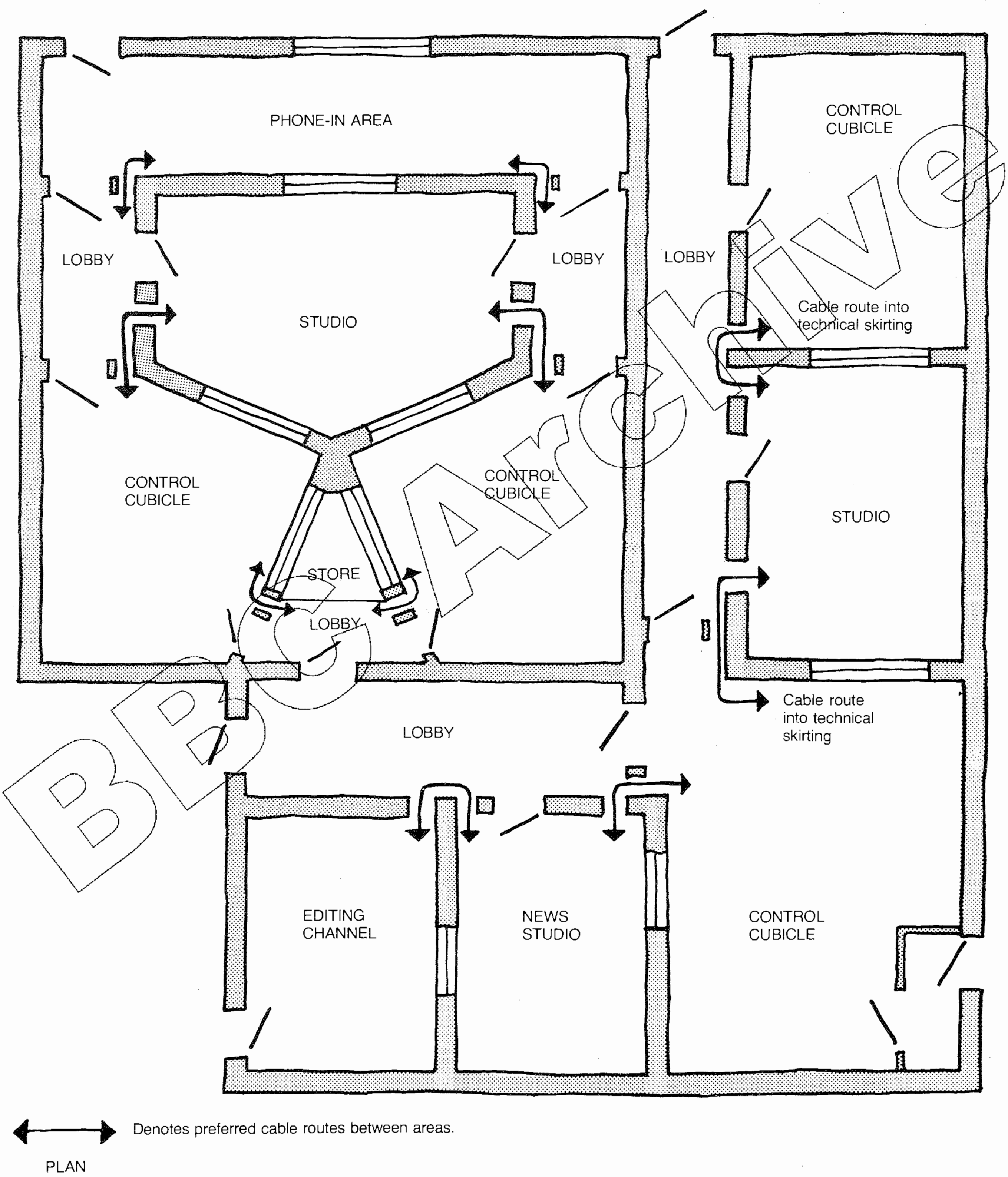
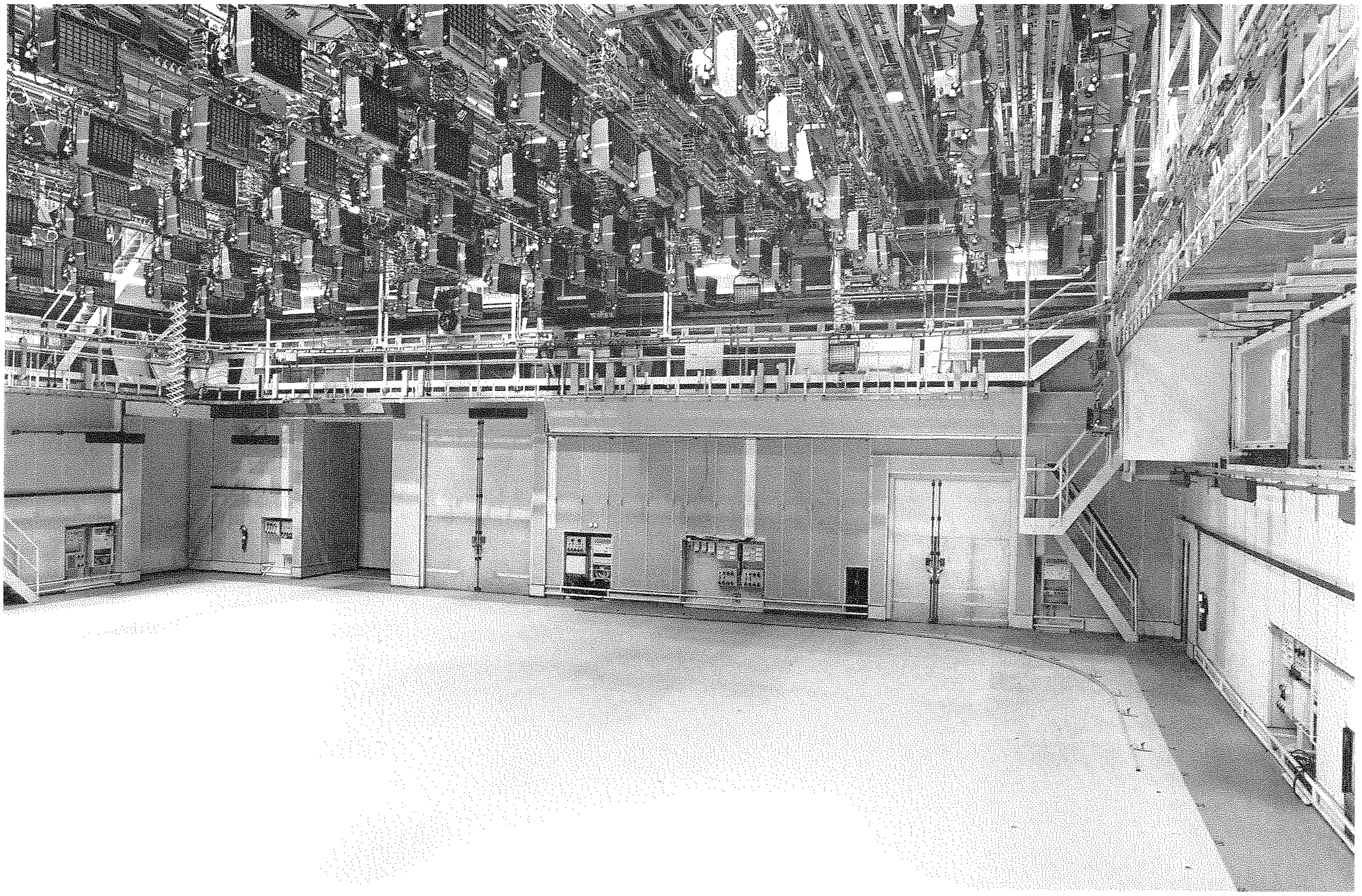
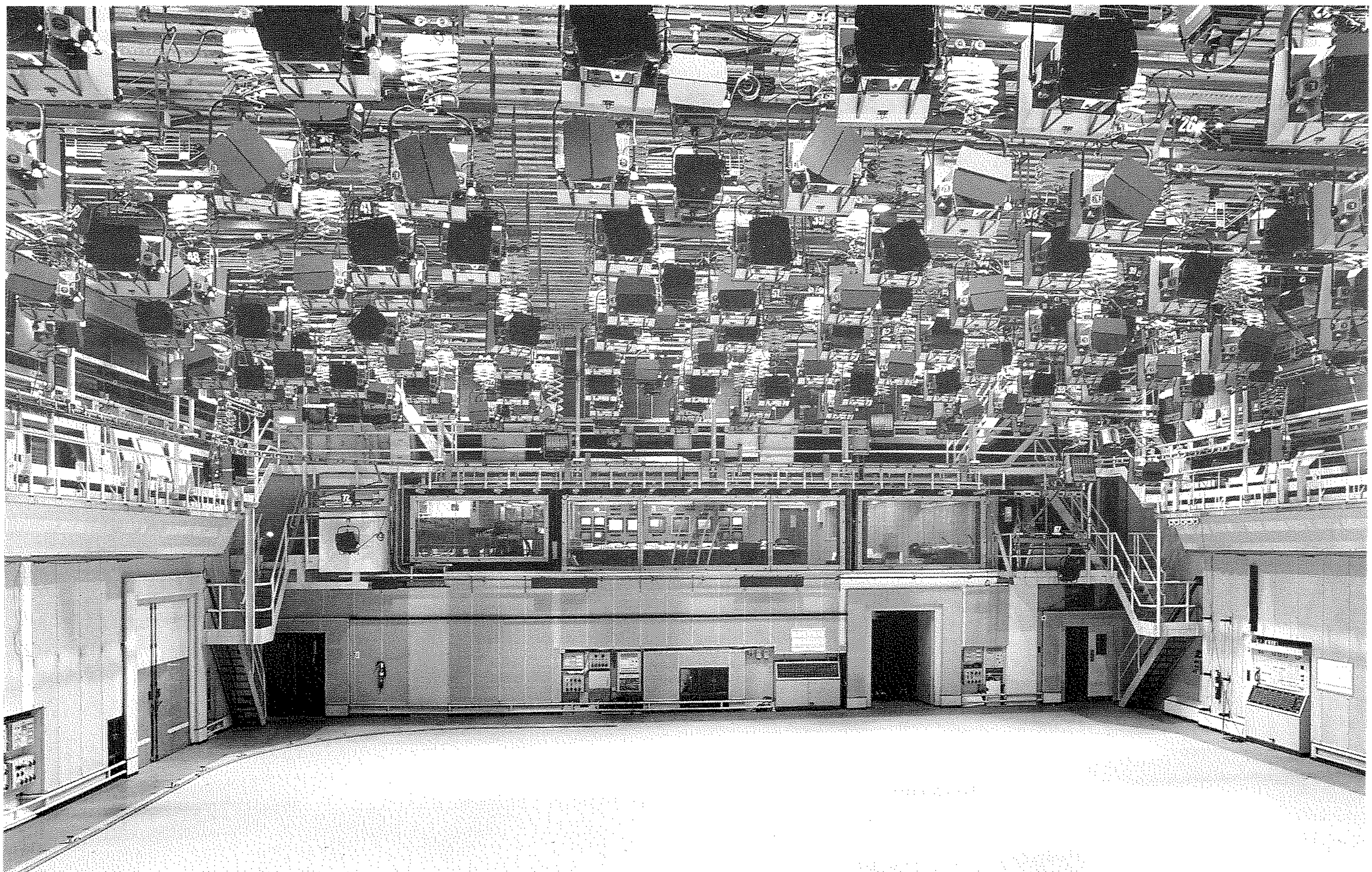


Figure 33 Combination of Plans for In-Line and Square Format layouts for BBC Local Radio Stations showing preferred cable duct routes





Typical Television Studio

SECTION 3 ROOM ACOUSTICS

ILLUSTRATIONS

PHOTOGRAPHS

3.1 Introduction

In any building designed for broadcasting or recording the need for the early consideration of room acoustics cannot be stressed too strongly.

Good acoustics are a pre-requisite of high quality broadcasting and consequently room proportions, dimensions and the provision of acoustic treatment within each space are of paramount importance and have to be chosen with great care.

The wide range of programmes broadcast on both radio and television channels requires studios with different acoustic conditions. These range from the reverberant conditions required for orchestral music to the relatively dead or 'dry' conditions needed for talks and discussion studios. Pop or light music requirements vary with fashion and drama studios require as much variation in acoustics within the studio suite as possible.

The acoustics of a studio or control room are usually controlled by applying materials to the room surfaces which have a variety of sound absorbing and diffusing properties. This is referred to as acoustic treatment.

Acoustic scale modelling techniques have been used by the BBC Research Department to assist in the acoustic design of large orchestral projects.

It is essential that the area and positioning of any acoustic treatment which has been modelled or is shown on any drawings is strictly adhered to and the treatment constructed precisely to the specification. Otherwise serious errors may occur in the overall acoustic performance which could result in additional costs being incurred and also delays in the studio or technical area operational dates. This applies particularly to the decoration of porous acoustic treatment, where the incorrect use of paint can seriously impair the absorptive qualities of the treatment, and to the provision of non-approved stretched fabric over the front of acoustic treatment. It should be noted that nothing should cover or be fixed to the front face of acoustic treatment other than as specified. This specifically applies to stretched fabric fixing systems, which must only be fixed around the edges of absorbers, and to permanent sets or screens in small television studios or review theatres where plywood or blockboard panels have been used in front of absorbers in the past instead of stretched fabric or canvas. Script racks, tape and record racks, notice boards, light fittings and even blackboards all come into the same category and must be taken into account at the design stage and not just fixed onto the face of the acoustic treatment as a result of last minute decisions. Cycloramas covering acoustic treatment in television studios should preferably be acoustically transparent or at least non parallel to an opposite surface. Concave arrangements of scenery can focus the sound, giving undesirable effects. These items, used incorrectly, can have disastrous results on the acoustics of a room.

The positioning of acoustic treatment is also critical. In so far as it is practicable, the sound absorbing material should be distributed around the walls and on the ceiling as evenly as possible, with regard to both the physical arrangement and its effect across the frequency spectrum.

Particular care should be given to the arrangements of the acoustic treatment between 1m and 2m from the floor especially in respect of the lateral symmetry. It is also important to consider the effect of reflections and flutter echoes which would result from the untreated surfaces such as cable trunkings and light fittings as well as the larger surfaces of doors, windows and equipment cabinets. Any resonances in equipment, fittings or acoustic treatment should be damped so that the rate of attenuation of their oscillations is considerably faster than the decay of sound in the room.

An approximate guide to the successful application of the above techniques can be obtained from the spread of reverberation times over different measurement positions in a room.

Where financial constraints limit the amount of acoustic treatment that can be used in a small studio, the minimum that can be specified successfully to avoid flutter echoes is to treat two adjacent walls with acoustic absorption and fit carpet on the floor or acoustic tiles on the ceiling. The acoustic treatment installed at microphone

sic Studio, Television Centre showing acoustic wall finishes

height in this situation must be designed to absorb sound at mid and high frequencies. With this limited design, care has to be taken to avoid an excess of mid and high frequency absorption compared with bass absorption; which will make the studio sound 'boomy'.

If interference ("comb filter") effects are to be avoided (and these can be especially problematical in the lower frequencies), attention must be paid to the amount of absorption available to attenuate the potential first reflections, especially around loudspeaker positions.

It should be noted that reflections from decorative finishes such as flat timber slats, can affect the quality of sound picked up by the microphones used close to them.

One particularly important point to remember is that all materials absorb sound to some degree; for example, plasterboard on a timber framing, to hide conduit runs, can provide unwanted low frequency absorption if not allowed for in calculations. It is imperative therefore that <u>any</u> proposed change of previously agreed materials, including furniture, must be notified to and approved by the acoustics consultant or designer.

Framing, supporting acoustic treatment or ceiling structures, can give rise to noise in a studio due to movement of material with differing thermal expansion properties being in contact with each other. Such systems must be chosen with care.

Asbestos based products incorporate fibres which can give rise to a health hazard. Such materials must not be used in BBC buildings under any circumstance.

3.2 Reverberation Time and Tolerances

(i) Reverberation Time (Figure 34)

The reverberation time is the only objective measure of the internal acoustic conditions within a room which is reasonably well understood, but it is, at best, a poor guide to the subjective acoustic environment. Many proposals for alternative or additional measurements have been made over the years but none can, at present, be interpreted subjectively, at least in small rooms. There is some good evidence that these alternatives are meaningful in concert halls and other large spaces, but such rooms are rare within the BBC.

This problem was recognised by the authors of EBU R22-1985(E) who did, however, give some general guidelines. If followed, these guidelines are likely to lead to satisfactory conditions but there are no guarantees.

To achieve the desired reverberation time in a studio, calculations are made using the Sabine/Eyring formula, which has been found in practice to give a more accurate prediction of the reverberation time in studios than the Sabine formula. The materials are chosen by the acoustics consultant and for most purposes the reverberation time should not vary much from high to low frequencies; however a bass rise is permissible in small talks studios.

Figure 34 illustrates recommended reverberation times for BBC Sound and Television Studios. Whilst there are many aspects of internal acoustics (for example flutter echoes) that cannot be quantified numerically these criteria have been produced as a guide for most situations and the room should match the curves as closely as possible.

In practice, though the final result rarely satisfies the design criteria at all frequencies, it may still prove satisfactory in use. The tolerances described below are intended to set a practical limit beyond which remedial action would be necessary.

These tolerances, illustrated in figure 35 are relevant to talks studios and all control rooms for Radio Broadcasting and also to sound control rooms for Television. The requirements for other areas will be discussed at the end of this section.

Reverberation time should be measured using 1/3 octave band limited pulses of warble tone or noise (exceptionally, impulse measurements may be used). The average result for several microphone positions should be calculated and plotted against frequency in 1/3 octave bands. From this curve the average reverberation time in the band 250 Hz to 3.15kHz should be calculated. Also the percentage bass rise (relative to the 250Hz to 3.15kHz average) at frequencies below 250Hz should be calculated and the variation with frequency should be noted.

(ii) Tolerances (Figure 35)

The allowable tolerances for programme areas are:-

Most critical areas will have an individual reverberation time design criterion and set of tolerances. These may include some frequency dependent features. However, there is a large class of areas which usually have the same specification and tolerances, namely relatively small studios used for voice only and many rooms in which sound quality assessments or sound control functions are carried out. The description of this criterion is given here as an example. Other types of areas will be subject to the same general controls and limitations, even though the numerical details will differ.

In setting these tolerances it is recognised that there are difficulties in the design of some rooms and the measurement of reverberation time at low frequencies. Accordingly, the tolerances have been divided into three frequency bands. (All frequency ranges are inclusive).

Control Room criterion:

Overall

The achieved reverberation time averaged over the frequency range 200 Hz to 3.15 kHz shall lie in the range 0.20 to 0.25 s. Whatever average value is actually achieved, the remaining tolerances are expressed relative to this achieved average, Tm.

Mid Frequencies

In the frequency range 200 Hz to 3.15 kHz every frequency-band average value shall fall within the range 0.8 Tm to 1.2 Tm.

Low Frequencies

In the frequency range 50 Hz to 200 Hz every frequency-band average value shall fall within the range bounded by the line 0.8 Tm and a straight line (on a linear scale of reverberation time) drawn from 1.2 Tm at 200 Hz to 2.5 Tm at 50 Hz.

High Frequencies

In the frequency range 3.15 kHz to 10 kHz every frequency-band average value shall fall between the lines bounded (i) on the higher side between 1.2 Tm at 3.15 kHz and Tm at 10 kHz and (ii) on the lower side between 0.8 Tm at 3.15 kHz and 0.6 Tm at 10 kHz.

Significant secondary (dual-slope) decays are not permitted at any microphone position or in any frequency band. The criterion of significance is if the reverberation time over the range -20 to -35 dB (relative to the steady-state sound pressure level) differs from that over the -5 to -20 dB by more than a factor of 2:1. The primary result shall be that over the -5/-20 dB range and the preferred means of presentation is by showing a subordinate point on the results. If the ratio is more than 2 then this shall be deemed to be unacceptable.

The allowable tolerances for 'Non-programme areas' are:-

Non-critical areas almost never have criteria for reverberation time. However in some cases, usually in order to control the internal environment for the room's occupants, it is desirable to specify an upper limit to the reverberation time. This may also be a function of frequency.

For reverberation time criteria it can be demonstrated that there is little need to specify a reverberation time outside the range 50Hz to 4kHz. In all but the largest studios the wavelength of sound below 50Hz will be greater than the dimensions of the room and thus reverberation has little meaning. In the case of orchestral studios, large drama studios or television studios the normally specified average reverberation time shall apply to these lower frequencies. At frequencies above 4kHz unavoidable absorption from fabrics and from the air will normally control the reverberation adequately. However for completeness it shall be required that the reverberation time shall not exceed the 250Hz to 3.15kHz average by more than 10%. There is no lower limit above 4kHz.

3.3 Studio Dimensions and Room Modes

Whilst the overall size of a studio or cubicle is determined by production needs, its proportions should be carefully

considered for acoustic reasons. Rooms which are square or (even worse) cube-shaped must be avoided at all costs. Generally, it should not be possible to express the ratio of length: breadth, length: height, or breadth: height in, or very close to, small whole numbers. This is to avoid many of the room's main natural resonances occurring at coincident frequencies, which will cause coloration of the sound.

This rule does not apply in rooms that are nowhere near rectangular; however if surfaces are only slightly angled (for example to avoid flutter echoes) it must still be followed. It is particularly important to take note of this in small and medium sized rooms.

Where a choice of room dimension is possible, there are a number of rules for selecting the proportions that will ensure a reasonably even spread of natural resonances. One that has stood the test of time is the "Golden Ratio" of 1 : $2^{1}/_{3}$: $2^{2}/_{3}$, or approximately 1 : 1.26 : 1.6. Any of the factors in this ratio may be multiplied by integers; e.g. 1: 2.52 : 1.6 is equally acceptable.

More recent work has shown that there are ranges of room proportions which give particularly good low-frequency mode distributions.

In relation to the room height, some of these proportions are $1.14 \pm 0.1/1.4 \pm .14$.

3.4 Flutter Echoes (Figure 36)

A flutter echo is the name for an audible resonance that occurs when sound is reflected to and fro between a number of hard and acoustically reflective surfaces, repeatedly retracing the same path. It is so called because the reflections can sometimes be heard separately following a sharp sound such as a handclap.

Depending on the time between successive reflections this may make either a fluttering die-away or a metallic ring.

In rectangular rooms, flutter echoes are almost certain to be a serious problem if there are great differences in sound absorption, particularly at high frequencies, between the directions of length, breadth and height. For example in a room which has a carpet (which absorbs sound travelling vertically) and only one pair of opposite walls acoustically treated, a strong flutter echo will occur between the untreated pair of walls. The minimum amount of acoustic treatment that should be specified to ensure that a room does not have flutter echoes is therefore a carpet or an acoustic tiled ceiling, together with sound absorbing treatment on two adjacent (not opposite) walls.

Flutter echoes also are particularly likely to be troublesome in rooms that are generally very heavily acoustically treated; (e.g. sound control rooms and radio talks studios). They will occur between any opposite parallel reflective surfaces (such as windows) and may also occur in non-parallel arrangements where the sound is reflected more than once before retracing its path. These are illustrated in Figure 36.

High frequency absorption should be provided directly opposite hard surfaces, particularly between seated head and standing head heights. For example, when a door is both parallel to and opposite a window, the face of the door must be carpeted. Alternatively one or both hard surfaces may be angled to bring them out of parallel. It has been found in practice that a total angle of 10 degrees is adequate; i.e., one surface may be angled by 10 degrees or both by 5 degrees in opposite directions.

A further alternative would be to provide non-absorptive diffusers instead of one of the hard surfaces.

Although not an acoustical consideration it should be noted that angled windows may give rise to troublesome optical reflections of lights. The cure is to use directional fittings that do not allow light to spill on to the windows.

3.5 Membrane Absorbers

Low frequency membrane absorbers incorporating roofing felt are no longer specified for BBC studios. Where they already exist it is normal practice to either replace them with alternative absorbers or where there is no money available for this, the fronts of the absorbers generally are carpeted.

This compromise retains what little low frequency absorption is left from the ageing process of the membrane materials and at the same time eliminates the high frequency reflections from the plain front surface. However the resulting fire hazard may not always be acceptable in some areas.

3.6 Panel Absorbers

All materials absorb sound to some degree and this is particularly the case with common panel materials such as plasterboard, plywood, blockboard and hardboard.

Thin panels absorb sound at low frequencies and the maximum absorption of a panel occurs at frequencies in the region of its resonant frequencies. These depend mainly on the mass of the material and its stiffness. The effectiveness of a thin panel is also influenced by the presence of an enclosed airspace behind the panel and its absorptive qualities can vary accordingly.

The inclusion of such materials in the design of a studio must be preconceived and not as a result of a late change. In one instance plasterboard over an airspace, installed as a last minute decision to hide electrical conduits, proved to be a highly efficient bass absorber and resulted in the majority of the low frequency absorbers in the studio having to be removed.

The absorption of such materials has therefore to be included in the calculations by the acoustics consultant from the outset.

3.7 Modular Absorbers (Figures 37, 38, 39, 40, 41 and photographs page 93)

Modular acoustic absorbers were first used within the BBC in 1967 when a standard form of mass produced acoustic treatment was required for local radio stations. This system comprises a number of standard modules in four different sizes giving a range of absorption characteristics from which suitable choices can be made for the treatment of individual studios and control rooms.

There are three main advantages of fixed module sizes. This first is that the architect designing the room can provide the mounting frames before the detail of the treatment is finalised. The second is that the treatment can be prefabricated, usually at a lower cost by a subcontractor away from the building site, thus saving both time and money. The third advantage is that subsequent changes, either immediately after construction if the treatment was initially incorrect or during later refurbishment, can easily be made.

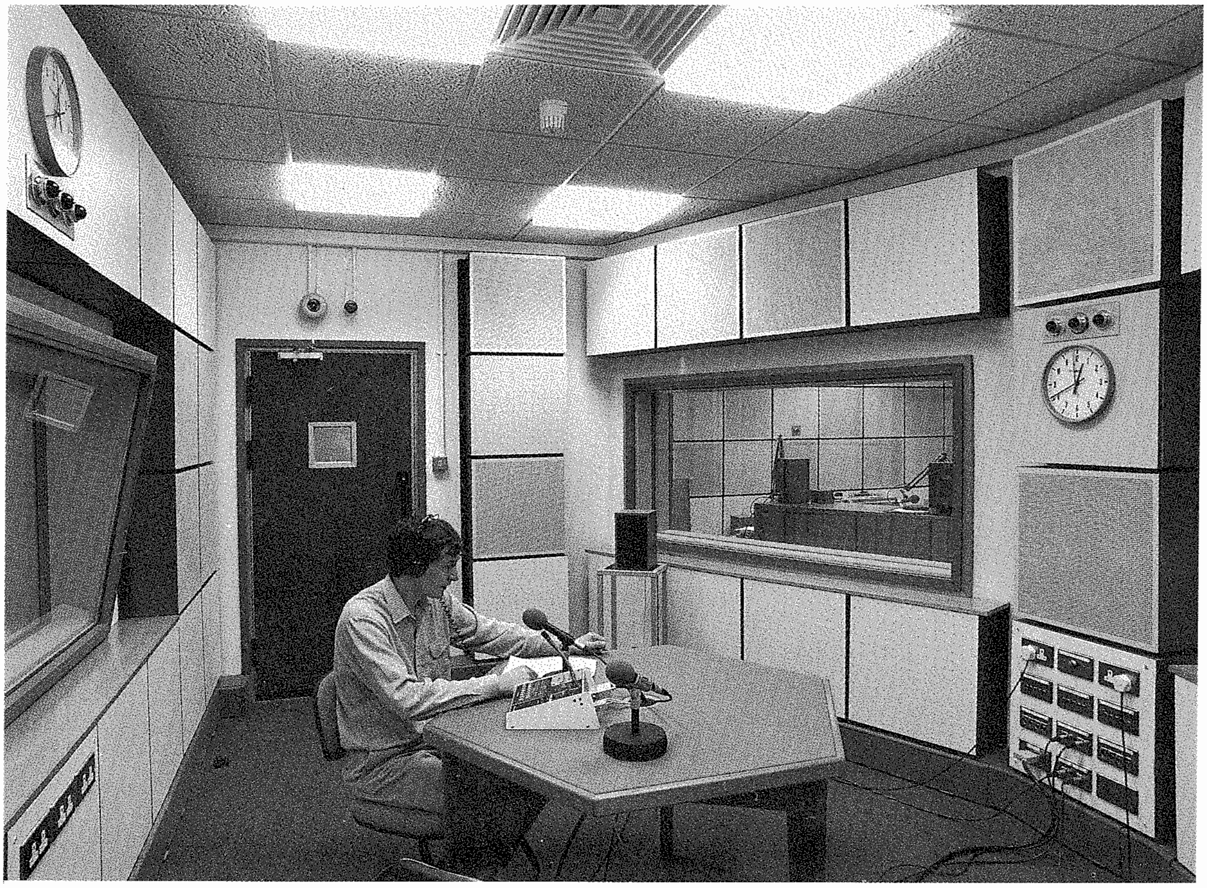
The original design for modular absorbers was based on a 600mm grid and it was decided that a 580mm square absorber with a 20mm spacing between units provided enough space for fixing to maintain this grid.

The treatment is designed on the principle of mineral wool over a partitioned airspace and the degree and type of absorption is varied by the use of different surface finishes.

The 580mm square absorbers are generally available in three differing depths, 184mm, 108mm and 215mm plus front finishes. These are known respectively as types A, B and C and the facial finish is identified by numerals, e.g. an A2 absorber is 184mm deep and has a 0.5% open area perforated hardboard cover whereas an A3 absorber is the same depth but has a 20% open area perforated hardboard cover.

One minor difficulty with the A-size module in very small rooms is the depth, which at 184mm can reduce the available floor space significantly. In this respect, the B-size module, which is approximately 108mm deep, is better, though often acoustically less satisfactory.

In practice, for the acoustic treatment of the majority of small and medium sized rooms two modules only are in common use. These are the "A2" and the "A3" modules. The A2 module is a relatively narrow-band, low-frequency sound absorber which uses the front-panel as an acoustic mass element resonating with the compliance of the airspace enclosed behind. The A3 module consists essentially of a mineral-wool layer in front of an airspace; the resulting absorption coefficient is high for all frequencies above about 315 Hz. To compensate for the increased absorption of the air above about 4 kHz and the almost unavoidable presence of fabrics and other materials which have a rising absorption characteristic above 1 or 2 kHz, the A3 module has a low-pass filter in the form of a



Typical Local Radio Studio and Control Cubicle showing use of Modular Absorbers

perforated hardboard front face with about 20% open to total area ratio. These two modules are complementary to each other and when used in approximately equal numbers provide a high and reasonably uniform absorption coefficient over a significant part of the audio frequency range. Together they provide a sufficiently flexible method of providing acoustic treatment for a wide range of room types.

A further common absorber type which is identified as type D2 is available as a double module 1180mm x 580mm x 292mm deep overall. This behaves similarly to the A2 module but has the advantage of a lower resonant frequency. It is generally of use in larger studios, say for music.

The method of fixing the absorbers to the wall is either by four mirror plates which are mounted on the hardboard back of the absorber and fixed by screws onto 50mm x 32mm battens on the wall or by four angle brackets which are fixed to the sides of the absorbers and screwed to the 50mm x 32mm battens. The fixings are staggered to enable the absorbers to be fixed alongside each other with only a 20mm gap between them. Where modular absorbers are used on the ceiling the battens supporting them must be securely fixed to the structure to avoid the possibility of the pulling loose and sagging under the weight of the absorbers.

A standard 'A' type absorber weighs 6 kg. Where a more positive fixing is required on the ceiling, bearing in mind that the rear fixed mirror plates are only screwed into the end grain of the plywood sides, fixing in the form of angles or brackets should be screwed direct into the plywood sides with the absorbers set in between the battens.

Whilst on the subject of fixing things to modular absorbers it must be stated that whilst it is permissible to cut out small sections from the back of standard A2 or A3 absorbers, provided that any hole is fully sealed around conduits etc., no holes must be made in rear of the A8 or A9 units. Nor should any holes be made in the front of any acoustic absorber, or anything fixed to the front or sides of any absorber, other than the support fixings referred to above.

Conduit drops should be sited behind the absorbers hence the 32mm batten which allows sufficient space for a 25mm conduit plus fixing.

Where modular absorbers are sited below observation windows and the fixing battens are vertical, it is essential that a board or other covering surface be provided over the absorbers to avoid items falling down the rear of the treatment.

The type A and B modular absorbers vary only in depth and they are manufactured in accordance with the following typical specification.

Modular absorbers types A1, A2, A3, A4, B1, B2, B3 and B4. (See Figures 37 and 39).

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a) The absorber shall be constructed with sides of 10mm plywood to BS 1455, butt jointed pinned and glued, or comb jointed and glued. The back shall be 6mm oil tempered hardboard to BS 1142 part 2 type TE weighing not less than 6 kg per square metre glued and pinned to the sides. An interlocking cardboard or hardboard partition shall be inserted to divide the interior of the box into voids 100mm square, the partitions being sufficiently rigid to maintain their integrity and to support the absorbent layer without appreciable deflection.

b) The front shall be 3mm oil tempered perforated hardboard to be glued and pinned to the sides of the absorber.

c) For absorbers type A2 and B2 the open area of the front panels shall be approximately 0.5% (one half per cent) with 3mm holes at 38mm centres. An unperforated border approximately 20mm wide shall be left around the edges of the front panel.

d) For absorbers types A3 and B3 the open area of the front panel shall be approximately 20% (twenty per cent) with 3mm holes at 6mm centres. An unperforated border approximately 20mm wide shall be left around the edges of the front panel.

e) There shall be a 30mm thick layer of mineral wool between the front cover and the partition, consisting of glass or silicaceous material bonded together with

resin or other suitable permanent bonding agent.

f) For absorbers types A2 and B2 the mineral wool shall be semi-rigid slab of density 40 to 60 kg per cubic metre.

g) For absorbers types A1, A3, A4, B1, B3 and B4 the mineral wool shall be rigid slab of density 140 to 150 kg per cubic metre.

h) Absorbers to be wall-mounted shall be fitted with four rear mounted mirror plates. Any absorbers to be ceiling mounted should be fitted with four side mounted metal angle fixings as specified. Fixings shall be at staggered centres.

i) All timber including hardboard and plywood is to be fireproofed unless otherwise specified.

The schedule of finishes for the fronts of the types A and B absorbers is as follows:-

A1 and B1. 12.5mm or 25mm square galvanised weldmesh in front of the mineral wool with an open-weave approved fabric covering the mineral wool.

This absorber is designed as a physically robust wideband absorber for use in Television studios with good absorption from 80 Hz upwards for the A1 and 125 Hz for the B1. (See Figure 41 for typical absorption coefficients).

A2 and B2. 0.5% open area perforated hardboard; generally manufactured with 3mm diameter holes punched at 38mm centres.

This absorber is used as a low to middle frequency absorber with peaks of absorption at 100 Hz and 125 Hz for the A2 and lower peaks around 125 and 250 Hz for the B2.

(See Figure 41 for typical absorption coefficients).

A3 and B3. 20% open area perforated hardboard; generally manufactured with 3mm holes punched at 6.0mm centres.

This absorber is used as a middle to high frequency absorber with good absorption above 100 Hz for the A3 and 250 Hz for the B3.

(See Figure 41 for typical absorption coefficients).

A4 and B4. 12.5mm chicken wire. This is occasionally used behind fixed curtaining.

A5 and B5. Stretched fabric. All fabrics must be inherently fireproof.

Stretched fabric can be used in two forms: Firstly as a decorative finish to mineral wool fronted absorbers and secondly to provide an aesthetic cover to perforated hardboard absorbers.

The choice of fabric, method of fixing and, most important of all, the spacing of the fabric in front of an absorber must be approved by the acoustics consultant as all of them can influence the predicted absorption characteristics of any absorber.

Modular absorbers types A8 and A9. (Figure 38).

A8 Wideband Modular Absorber: 20% open area perforated hardboard; generally manufactured with 3mm holes punched at 6.0mm centres.

A9 Wideband Modular Absorber: 12.5mm square galvanised weldmesh or 12.5mm chicken wire in front of the mineral wool with an open-weave approved fabric covering to the mineral wool. The fabric can be placed either onto the face of the mineral wool or stretched 6mm in front of the absorber.

Both the A8 and A9 wideband modular absorbers are available only in the single 'A' type depth of 184mm. The absorbers were designed in 1982 by the BBC Research Department who realised that despite the fact that the A2 and A3 modules had been used together for many years, they had three main defects. The first is that the two modules are not truly complementary and together they have an excess of sound absorption around 400 Hz. This gives rise to lower reverberation times around 400 Hz than at high and lower frequencies in areas treated with these two modules. The second defect is that as each of the modules is effective only over part of the audio frequency range the total surface area of treatment required is about twice that which would be required if one module

was effective over the whole audio frequency range. In some small areas it is difficult to find sufficient free wall or ceiling space for the required quantity of acoustic treatment. The third defect is that the type A2 absorber, because it is effective only at low frequencies, is an efficient reflector of high-frequency sound energy. The front surface of the A2 is essentially unperforated and flat; the resulting high frequency reflections are specular rather than diffuse. This causes great difficulties, especially in control rooms equipped for stereo where the flat surfaces of the observation window, equipment bays, control desk, untreated wall surface as well as the front panels of the low-frequency acoustic treatment, all combine to produce a great deal of specular reflection.

It was therefore decided to design a new absorber which combined the best features of the A2 and A3 modular absorbers but without the excessive absorption at 400 Hz which had previously been provided by the combination of A2 and A3 absorbers.

The outcome of the BBC Research Department's deliberations and experiments are shown in figures 38 and 41 which illustrate the construction and performance of the absorbers.

The basic module comprises a standard A-Size box with an internal unperforated panel of 3mm thick hardboard, spaced so as to enclose an airspace 110mm deep. This internal panel is supported in position by being lightly pinned to an internal beading which is continuous around the perimeter of the panel and which is glued and pinned to the internal side surfaces of the box. The space in front of this panel (62mm deep) is filled with two layers of 30mm thick mineral wool, the front one being high-density approx 150 kg/m^3 and the second one low-density approx 50 kg/m^3. The whole assembly is enclosed either by a 3mm thick perforated hardboard front panel with 20% open-area for the A8 absorber or by a galvanised weldmesh or chicken wire front for the A9 absorber. Both units have a 6mm hardboard rear panel. Two holes of 38mm diameter each are drilled in the side panels in such a position as to join the enclosed rear airspace and the outside of the module. Each of these holes is covered by layers of gauze bandage fabric with a total flow resistance of 20 rayls.

The A8 and A9 absorbers are fixed in the same manner as all other modular absorbers but the modules must be laid out so the holes in the sides of the absorbers are not facing each other. Nor must they be covered over by the sides of absorbers being in contact with each other.

Modular Absorber Type C (Figure 39)

The type C modular absorbers vary from the type A and B absorbers in that they are covered with 12.5mm square galvanised weldmesh and have a 50mm layer of fabric covered high density mineral wool as the absorbing layer. The type C2 absorber incorporates a layer of 3mm thick 0.5% perforated hardboard immediately behind the mineral wool. This means that the partitioned airspace behind the mineral wool is 155mm deep for the C1 absorber and 152mm deep for the C2 unit.

Modular Absorber Type D2 (Figure 40)

Modular absorbers type D2 are designed to provide low frequency absorption, generally in large studio areas. Their construction is similar to an A2 modular absorber but is constructed as a larger and deeper module, 1180mm x 580mm x 292mm deep overall. Typical absorption coefficients are shown in Figure 41.

The specification for a D2 absorber is as follows:-

a) The absorber shall be constructed with sides of 10mm plywood to BS 1455, butt jointed pinned and glued, or comb jointed and glued. The back shall be 6mm oil tempered hardboard to BS 1142 part 2 type TE weighing not less than 6 kg per square metre glued and pinned to the sides. An interlocking cardboard or hardboard partition shall be inserted to divide the interior of the box into voids 100mm square, the partitions being sufficiently rigid to maintain their integrity and to support the absorbent layer without appreciable deflection.

b) The front shall be 3mm oil tempered perforated hardboard, to be glued and pinned to the sides of the absorber.

c) The open area of the front panels shall be approximately 0.5% (one half per cent) with 3mm holes at 38mm centres. An unperforated border approximately 20mm wide shall be left around the edges of the front panel.

d) There shall be a 30mm thick layer of mineral wool between the front cover and the partition, consisting of glass or silicaceous material bonded together with resin or other suitable permanent bonding agent.

e) The mineral wool shall be semi-rigid slab of density 40 to 60 kg per cubic metre.

f) D2 absorbers to be wall or ceiling mounted shall be fitted with four side mounted metal angle fixings as specified. Fixings shall be at staggered centres.

g) All timber including hardboard and plywood is to be fireproofed unless otherwise specified.

In certain situations purpose-made modular absorbers may have to be designed to suit special circumstances and may vary in depth and size from the absorbers examined in the preceding paragraphs. In these cases detailed drawings and specifications will be provided by the acoustics consultant.

Paint should only be applied to the external face of the absorber with a paint roller and care should be taken not to reduce the open area or diameter of the perforations of the front cover. Should this happen it is essential that the holes be opened up again or the absorber fronts renewed. It is normal practice to paint the sides of the modular absorbers and the battens to which they are to be fixed a dark colour prior to the absorbers being installed.

Where light coloured fabrics are used over the fronts of modular absorbers it is advisable to paint the fronts of the absorbers a dark colour to prevent the apparent discoloration of the fabrics by the contrast behind the fabrics of the dark perforations, and gaps between the absorbers, against the light colour of the non perforate area of the hardboard front.

Care should also be taken to leave a plain margin around the sheets of perforated hardboard and to line up the perforations from absorber to absorber. One important point that should be borne in mind when applying high percentage open area perforated or slotted finishes to wall surfaces near eye level is that an unpleasant visual effect will be obtained with large unbroken areas which must therefore be avoided; this can be avoided by covering the treatment with a suitable, approved inherently fireproof fabric, or by careful use of decorative finishes or colours to break up the overall appearance.

3.8 Porous Absorbers (Figures 42, 43, 44 and 46)

(i) Introduction

Porous materials are used extensively by the BBC for sound absorption. Briefly, the absorption is due to energy lost through friction of air particles in the fibrous body of the material. The types of material most commonly used in BBC studio design to provide middle and high frequency absorption are mineral wool, glass fibre or heavy fabrics. These materials are very efficient in absorbing high frequency sounds but, with the exception of fabrics, are generally unpleasant to look at and get dirty very quickly. In addition, these mineral wool and glass fibre materials can produce a skin rash on sensitive persons coming into contact with them. The installation of these materials is subject to recommendations from the Health and Safety Executive. The most efficient solution to the problem is to cover the materials with some form of facing e.g. perforated hardboard or metal panels, profiled timber slats, lightweight inherently fireproof open-weave stretched fabric or lightweight curtains. The amount and type of perforation has a very important bearing on the absorption that can be achieved by an absorber; generally speaking, the lower the percentage perforation - the less absorption of the high frequency sound, although the absorption of the low frequencies may be increased. It is important, therefore, to adhere to specified percentages and types of perforation. The two most commonly used

perforations in current BBC acoustic designs are 0.5% and 20% open area and these are usually provided by 3mm diameter holes punched at 38mm centres for the 0.5% perforation and 3mm diameter holes at 6mm centres for the 20% open area perforation. Both perforations have to be specifically perforated to order, as they are non-standard items. Consequently time has to be allowed for their supply.

Decoration of any perforated hardboard finishes to porous absorbers to be as described in the previous section 3.7.

Porous absorbers can be sub-divided into 5 groups and they are as follows:-

(ii) Mineral Wool Absorbers

The thickness of mineral wool and the depth of airspace behind it, together with the density of mineral wool govern the amount of absorption to be expected at low frequencies. Any air space is normally divided by hardboard partitioning into specified areas. The make and type of mineral wool is usually specified, but if not, it should be assumed that heavy density material of 144 - 176 kg/m^3 is required.

In all studio and technical areas any mineral wool treatment must be covered with an approved protective glass fibre, or other fireproof, fabric layer; this is usually sited between the perforated face and the mineral wool.

Mineral wool covered by polythene film loses its efficiency as an absorber particularly at high frequencies and must never be used unless clearly specified by the acoustics consultant. For instance in some external situations where acoustic treatment is open to the elements a SINGLE layer of thin polythene sheeting may be specified to protect the acoustic treatment from the weather.

Where uncovered mineral wool is used as a studio finish, primarily for television studios, any joints in the exposed material should not be left visible. This can be overcome by the provision of an approved inherently fireproof fabric cover as a surface finish behind the weldmesh.

These absorbers provide a range of middle to high frequency absorption which is varied by choice of cover, density of absorbing material and depth of airspace. Typical absorptions coefficients for porous absorbers are illustrated in Figure 46.

The basic absorbers are simply fixed direct onto the wall and/or ceiling surface with the mineral wool positioned between timber battens. The absorber is then finished with a specified covering.

More complex absorbers which incorporate an airspace behind the mineral wool are fixed to a battening system.

These absorbers can all be manufactured in situ or prefabricated off site.

Where absorbers with hardboard backs are spaced off the wall or ceiling surface the additional absorption provided by the hardboard must be taken into account in the overall acoustic design.

Where stretched fabric panels are preferred for aesthetic reasons to high percentage open area finishes an approved open weave, inherently fireproof fabric, spaced no more than 6mm in front of the absorber, may be used.

All fabrics used for curtains or stretched fabric panels must be approved by the acoustics consultant as the additional sound absorption which they provide has to be included in the acoustic design.

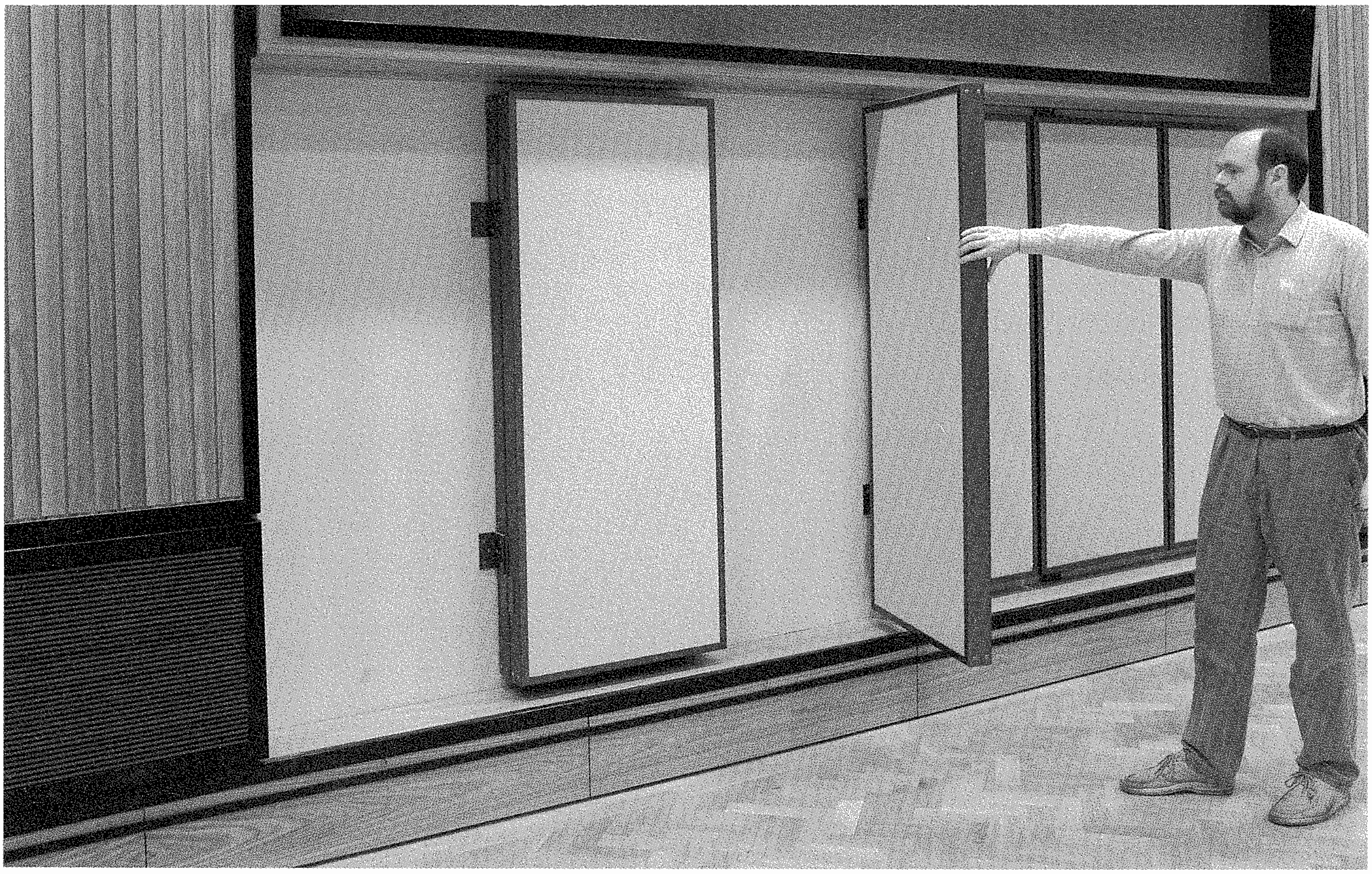
ALL TIMBER AND HARDBOARD MUST BE FIREPROOFED.

(iii) Wideband Porous Absorbers (Figures 43, 44, 46 and photograph page 99)

Wideband porous absorbers are generally specified for television studios. Their construction is similar to that detailed in the previous group 3.7 (ii), the only difference being that the airspace behind the porous absorption is deeper and is partitioned horizontally and vertically with interlocked hardboard partitions.

The treatment is constructed in situ and provides efficient wideband absorption from 63 Hz upwards.

Typical wideband treatment with slatted timber finish.



Hinged Absorbers

Proprietary modular absorbers formed in metal are sometimes specified for small TV studios. These absorbers are available in a number of modules each of which has varying absorption characteristics. Care must be taken with the selection and positioning of these absorbers to achieve the desired reverberation time in a studio. They must also be installed in full accordance with the manufacturer's instructions.

(iv) Acoustic Wedges

Acoustic wedges formed in mineral wool or glass fibre, with a protective fabric outer covering, are provided in anechoic chambers and other specialist installations within the BBC where tests are required to be carried out in acoustically free-field conditions. They are also sometimes specified for use in dead rooms in drama studios where a simulated outdoor acoustic is required.

Wedges are manufactured by a number of manufacturers with the cut-off frequency being always dependent on the length of the wedge.

The absorbers are fixed to the walls and ceilings by proprietary fixings and care must be taken to ensure that they are installed precisely according to the manufacturer's specification. It is also important to provide protection for the ends of the wedges where the likelihood exists of damage by the occupants of the area.

This protection can be in the form of an open metal mesh or grid provided that it does not resonate.

(v) Acoustic Blankets/Quilts

Acoustic blankets made up from layers of mineral wool reinforced with chicken wire and encased in fabric are available for use for acoustic wall and ceiling treatment in low cost studio projects and temporary installation. The blankets can be hung from a scaffolding framework with the blanket tied back at regular intervals. The deeper the airspace behind the blankets the wider the frequency range over which useful absorption can be achieved. The material requires a protective and/or decorative layer in front of it to avoid damage from scenery etc. and lightweight curtains or cycloramas are normally provided in front of it.

(vi) Functional Absorbers

Functional absorbers, or noise absorbers as they are more commonly known, are basically designed to provide efficient noise control in areas such as apparatus rooms, equipment areas, scenic and mechanical workshops, factories, etc. where machine noise is excessive. Absorbers suspended from ceilings over noisy equipment can provide an economical solution to reverberant noise within an area.

The term "functional absorber" has come to mean the use of panels or sheets of porous material, covered in fabric or other protective surface, which are mounted or hung, usually on wires, so that both sides of the absorber are exposed to the sound field.

Intuitively it would be expected that such an absorber would be most effective for the higher audio frequencies: this is not necessarily a severe disadvantage in industrial noise control, where a reduction of the sound pressure level (spl) at such frequencies can bring, for example, increased speech intelligibility as well as a less unpleasant working environment. The use of such techniques for studio acoustic treatment offers the possibility of providing a relatively large total amount of sound absorption while minimising the area of wall surface occupied by the treatment: indeed, the surface to which the functional absorber is fixed can itself carry more acoustic treatment, particularly if the functional absorber is placed some distance from it (for example, suspended well below a ceiling which itself carries absorbers). If this approach is to be adopted, however, reasonably accurate assessments of the absorption characteristics of particular arrangements of functional absorbers are required.

Tests carried out by the BBC Research Department using various configurations showed that panels of porous material arranged to project from the surfaces of a room, show in general a rising characteristic of absorption coefficient against frequency up to a certain value (typically 500 Hz - 1 kHz), above which the absorption coefficient remains constant.

At the lower frequencies (say below 250 Hz) absorption appears to take place, at least in

part, because the velocity (kinetic) component of the sound field causes air to pass through the absorber where power is dissipated by viscous friction. In this context, increasing the surface density of the absorber without altering its thickness or porosity, by loading it with relatively massive but acoustically transparent material (sheets of welded steel rods, for example), gives on average an increase of absorption coefficient of about 20% at these lower frequencies. At the higher frequencies (say about 1 kHz) absorption is mainly due to the potential (pressure) component of the sound field, which forces air into the surface layers of the absorber, against the compliance of the entrapped air, so that power is again dissipated by viscous friction. A neutral plane of zero velocity exists at the centre of the absorber, which behaves as if it had twice its actual surface area and half its thickness, backed by a massive rigid surface. The frequency range 250 Hz - 1 kHz may be regarded as a region of transition between these two mechanisms of sound absorption.

The absorption coefficient of an individual absorbing panel depends considerably on the arrangement of the absorbers in the room: in general, the absorption coefficient rises as the spacing between the panels is increased. There is some evidence to suggest in addition, that for a given absorber size and spacing, the absorption coefficient of an individual absorber increases with the volume of the treated room. In the case of rectangular absorbers, the present results suggest that no difference in absorption occurs when the absorbers are arranged with either their long or their short dimension normal to the room surface, although other work suggests that a slight increase in absorption (at least at higher frequencies) is obtained with the long dimension normal to this surface.

There is no evidence to suggest that functional absorbers can be arranged to give absorption predominantly at low or mid-frequencies: the results of individual tests certainly show "peaks" and "troughs" of absorption at these frequencies. Furthermore, these peaks are not well controlled, but depend markedly and in a not easily predicted manner on individual absorber arrangements.

3.9 Variable Acoustics (Figure 45 and photograph page 99)

The most common systems of variable acoustics currently used in BBC studios are with acoustic screens or hinged wall panels.

Acoustic screens designed by the BBC and described in section 5.2 provided a simple system of variable acoustics with a number of different screen modules and roof units being available.

Recently, hinged panels manufactured in the same manner as the screens have been applied to wall surfaces in drama and music studios.

The panels are made up with a reflective side of plastic laminate faced chipboard and two layers of differing density mineral wool, covered with approved stretched fabric, on the dead side.

The panels are initially installed alongside each other with the dead side facing outwards. To provide a brighter acoustic condition the panels are simply covered by the adjacent hinged panel thereby exposing the plastic laminate face and plastered wall surface of the studio wall. This system provides a number of alternatives in the acoustics ranging from the brightest to the deadest conditions.

Allowance has to be made in the acoustic calculations for the low frequency absorption provided by the chipboard backs acting as panel absorbers in the live acoustic condition.

3.10 Helmholtz and Slit Resonators

These absorbers are seldom specified for BBC studios due to the problem of siting them precisely where they are required, but when they are, a special detail will be supplied. Dimensions and construction of these units are critical to one millimetre and particular care must be observed in their erection and location.

3.11 Acoustic Tiles, Acoustic Panels or Boards and Acoustic Plasters

(i) Acoustic Tiles

Suspended acoustic tile ceilings are provided in many studios or technical areas, not only

for acoustic purposes but to hide ventilation ducts and other services. Acoustic tiles together with their method of installation or application must be specified or approved by the acoustics consultant and installed in full accordance with the manufacturer's instructions. The acoustic absorption coefficients of acoustic tile ceilings can vary to a considerable degree and this is mainly due either to the composition of the tile itself or whether or not a large airspace is provided behind a tiled ceiling.

It is essential that when acoustic tiles are installed in studio areas neither the tiles nor their supporting system audibly resonate when excited by sound waves. The acoustic tiles can be fixed in either a concealed or a lay-in grid but it is imperative that the grid system supporting the tiles is hung from the structure on rigid angle hangers rather than on the standard wire suspension hangers normally supplied.

Acoustic tiles installed in studio areas are generally 600mm square and the grid supporting them is generally fully interlocking and designed to incorporate light fittings and ventilation diffusers.

Large voids above acoustic tile ceilings may require acoustic treatment to at least two adjacent wall surfaces to avoid resonances occurring within the void being audible in the room below the ceiling.

Acoustic tiles are provided in other areas besides studios with the intention of absorbing sound within the room and consequently reducing the overall noise levels. Some rooms that fall into this category are newsrooms, which require the maximum amount of absorption possible to all wall and ceiling surfaces and offices and other areas where a reasonably quiet environment is required but typewriters, telephones or teleprinters exist. Acoustic tiles can also be used to provide localised absorption around noisy equipment.

Tiles or plasters containing asbestos are not permitted in BBC premises.

Although not an acoustical consideration a point which has led to confusion and breakages in the past is that some acoustic tiles have to be taken down in a certain sequence and the first tile in the sequence is rarely readily identified. It is recommended that this tile be marked in such a manner as to be easily identified. This is generally in the form of a red dot in the corner of the relevant tile. This can also be used to identify service access points.

(ii) Acoustic Panels or Boards

Acoustic panels or boards are often used in studios, control cubicles and other technical areas to provide shallow acoustic wall treatment. They have the advantage over other forms of traditional shallow wall treatments in being pre-finished, easy to install and manufactured in large panels. 2700mm x 600mm or 2700mm x 1200mm are typical panel sizes compared with the 600mm x 600mm normal size of the acoustic tiles used in studio acoustic design.

This treatment is also ideal for use in newsrooms, sound lobbies, editing rooms, cutting rooms, machine rooms etc. where acoustic treatment is only required above desk top height. In these situations the panels can be cut in half, thereby reducing the costs of the acoustic treatment.

Fixing is generally with a concealed proprietary fixing system, fixed either onto timber battens or direct onto the wall surface.

Some materials are prone to damage and where heavy traffic or wear is anticipated and the likelihood of damage to panels exists, it is recommended that protective measures are taken. Chair rails or other materials should be fixed in front of the treatment at appropriate heights to protect it from impact damage.

(iii) Acoustic Plasters

Acoustic plasters are seldom used in BBC studio areas but should they be specified, the manufacturer's instructions regarding composition, build-up, overall thickness and surface finish must be strictly adhered to.

3.12 Flooring

All surface finishes applied to studio floors must be installed in such a manner to ensure that there are no voids between the floor finish and the sub-floor.

This particularly applies to wood-block or wood-strip flooring which must be fully bonded direct onto the concrete sub-floor. The existence of any voids under such a floor can significantly alter the degree of absorption provided by the floor. In addition shrinkage and wear over a period of time can cause the floor finish to move or creak thus causing a disturbing noise in a studio.

3.13 Carpets and Carpet Tiles

All carpets and carpet tiles absorb sound to some degree. The absorption is dependent upon a number of factors namely the composition and density of the weave used in the manufacture of the carpet or tile, its pile depth, backing and most important of all whether or not an underfelt is used.

The carpets specified for BBC studios are Axminster or Wilton weaves of carpet on hairfelt underlay.

Alternatives to hairfelt, such as foamed underlays are not acceptable as they significantly reduce the absorption of the carpet. In some situations where impact noises to rooms below are a problem despite the presence of carpet in the upper room, then a double layer of hairfelt underfelt can help alleviate the problem.

In some cases, where less absorption is required a haircord carpet is sometimes specified.

Due to uneven wear and tear in control cubicles or sound control rooms it is the policy of some BBC studio centres to lay carpet tiles in the control cubicles. This enables the users rapidly to replace the tiles as and when they are damaged rather than replace a whole carpet each time.

Another solution to this problem which has been adopted in some T.V. control rooms is to lay a rubber mat or other hard-wearing floor surface under and around the control desk where heels or chairs damage the floor covering.

The carpet or carpet tiles must be anti-static.

In all cases the acoustics consultant takes the absorption of the carpet or carpet tiles into account in the acoustic calculations for an area. It is therefore essential that any change from the original specifications be notified to the acoustic consultant who can then adjust the calculations and quantities or types of other acoustically absorbing materials within a room to compensate for any change in absorption from the floor covering.

The use of carpet and carpet tiles in the acoustic design of studios or control cubicles is not confined only to floor surfaces; Walls, doors, dados, equipment bays, ventilation ducts and bulkheads are often covered with carpet to eliminate unwanted acoustic reflections.

Carpet is an ideal material for situations, such as walls in sound lobbies, where acoustic absorption is required which will withstand hard knocks from tape trolleys, musical instruments etc. and at the same time is easy to clean. This technique can be subject to fire regulations in certain buildings.

3.14 Stretched Fabrics and Curtains

(i) Stretched Fabrics (Figures 37 and 43)

Over the years the appearance of modular acoustic absorbers and other treatment using a perforated cover has become aesthetically unacceptable to both the architects and the users of areas so treated, and it has therefore become common practice to cover the fronts of such treatment with stretched fabric.

Investigations carried out by the BBC Research Department found that with acoustic treatment which absorbs most of the incident sound energy, that is, treatment which has a high absorption coefficient, lightweight fabric covers affect the performance of the treatment by only a small and probably insignificant amount.

However, with surfaces which absorb less than about 30% of the incident sound energy (the remainder being reflected) the fraction of sound energy absorbed by a combination of the surface and a lightweight fabric cover may be much greater than for the surface alone. The increase is dependent on the reflectivity of the surface, the resistance of the fabric and on the airspace separating the two as well as the frequency of the sound. With practical

methods of construction, the effect is only significant at high frequencies.

In the design of studios and control rooms with fabric-covered acoustic treatment, the effect of the fabric on the performance of the treatment must be considered in those cases where the fabric covers a surface which reflects a significant fraction of the sound energy at mid and high frequencies. To minimise the effect, within the frequency range usually considered, the airspace between the fabric and the surface should be as small as possible, preferably less than 6mm.

Fabric installed in any studio or control room must be approved by the acoustics consultant and be inherently flameproof.

Fabrics which are fireproofed generally lose their resistance to fire when they are cleaned and consequently require re-treating.

Proprietary fabric fixing systems are available using 6mm plastic extrusions and these should be used to install the stretched fabric finishes. It is essential that the plastic extrusions only be fixed around the edges of absorbers <u>NOT</u> across the face.

Although not an acoustical consideration it should be noted that spaces between absorbers and high percentage open area perforations produce dark areas or patterns behind a stretched fabric cover. It is normal practice to paint such treatment a dark colour, with the plastic fixing extrusion a similar dark colour, and select the colours of the fabrics bearing this point in mind.

(ii) Curtains

Curtains are sometimes included in the architectural design of studio areas and it is essential that any fabrics used be approved by the acoustics consultant who has to include them in the calculations for the additional absorption provided by the curtain. Heavy weaves and velours can provide significant absorption from 250 Hz upwards particularly when spaced away from a wall and lined.

Any curtain fabrics or linings used must be inherently flameproof or fireproofed. If a material is fireproofed it must be remembered that it loses its resistance to fire when the curtains are cleaned and consequently must be re-treated.

Double curtains with an airspace between them are provided in Drama studios to segregate different parts of the studio and they are manufactured with one 'live' side, generally in sail cloth or white scenic canvas and one dead side in heavy velour. The curtains are provided to give differing sound effects and operate on separate curtain tracks. A typical specification for a Drama Studio curtain is as follows:-

(a) One pair of curtains made up in white scenic canvas, with no fullness, curtains to be webbed at the heading with hooks at 300mm centres and chain weighted along the bottom.

(b) One pair of curtains in Velour gathered to 75% fullness and lined and interlined. Curtains to be webbed at the heading and chain weighted along the bottom.

The drama curtains specified above will only provide minimal acoustic separation between a live end and a dead end of a drama studio. One solution to this problem, which also provides more flexibility in the overall use of the studio, is to provide a folding partition between the two curtains which is only pulled shut when acoustic separation between areas is required.

3.15 Lighting Grids

Lighting grids in Television studios have become increasingly less transparent over the past few years from an acoustic point of view. The studio floor chosen for operational reasons, tends to be a hard reflective surface acoustically, therefore it is important that the lighting grid be as acoustically transparent as is structurally possible, otherwise excessive sound reflections will occur which will be detrimental to the broadcast quality of the sound.

The depth of the slats in the grid must be kept to a minimum and the overall percentage open area should not be less than 70%.

To reduce the problem caused by impact noise rubber pads should be provided at all loose or bolted metal connections over the whole area of the lighting grid and gallery.

3.16 Painting and Decoration

Although the painting and decoration of all types of acoustic treatment has been covered briefly in the previous sub-sections it is important to stress again that the incorrect application or use of paint can seriously impair the acoustic qualities of any absorber. The maintaining of the specified percentage open area of a perforated absorber is critical to the efficiency of that absorber and the filling up of any holes with paint must be avoided. Should this problem occur it is essential that the holes be opened up again or the absorber face renewed.

In all cases where perforated surfaces are to be painted, a paint roller should be used to apply the paint. Spray techniques should never be permitted as the paint will be absorbed by the acoustic lining behind the perforated surface.

Acoustic tiles should only be painted with a watery emulsion paint when they are redecorated.

Pores in the surface of the absorbent material are less likely to be blocked by this method.

The use of wire wool for rubbing down or cleaning surfaces in technical areas is strictly prohibited as the microphone or loudspeaker magnets can be contaminated by the particles of wire wool left behind on completion of the operation.

The choice of colours, particularly dark ones, can affect the lighting in some areas and can also have a psychological effect on the acoustic environment. Therefore colours should be chosen with care.

3.17 Modular Studios

The principles of the design of modular studios are outlined in section 2.9. The acoustic treatment within a modular studio or cubicle comprises a mixture of tuned panels and perforated metal sheeting over a mineral wool backing.

This combination of treatment enables the designer to control the overall response of a studio or cubicle and the internal surfaces are generally finished with stretched fabric panels in front of the treatment.

3.18 Outside Broadcast Vehicles

The principal difficulty in obtaining a good acoustic inside an outside broadcast vehicle arises from the small size of the enclosure. Since space is at a premium, there is usually no room to install deep low-frequency absorbers, and the increased reverberant sound field at low frequencies produces a subjective 'bass rise' which equalisation in the loudspeaker signals can only alleviate. In addition, there will be fewer room modes in a given frequency range as compared to a conventionally sized listening area. The resulting presence of pronounced standing wave patterns in the distribution of sound pressure through the enclosure can cause changes in the subjective quality with position in the room. Thus, for example, the sound mixer seated at the desk, and the producer standing behind him, may hear differences both in respect of the tonal quality and in the sharpness of stereo image of the programme material.

Calculations of sound absorption inside a vehicle can be made using conventional studio design practice in order to achieve a reverberation time characteristic consistent with good listening conditions. A design reverberation time from 250 Hz upwards of 0.2 sec. is used, but the characteristic actually achieved depends on the limitations of absorber area, disposition and type which are imposed by the small size of the enclosures under consideration, and also the requirements of individual vehicles (the amount of wall mounted equipment, for example). The small enclosure size is of particular importance in the lower frequency ranges. In the first place, the effect of room modes (eigentones) must be considered. Although for any room the number of modes in a given one-third octave frequency band increases with the band centre frequency, the number of modes in a band of particular centre frequency becomes smaller with a decrease in the size of the room.

In the 1960's and early 1970's the principal method used to obtain controlled sound absorption in a vehicle was by the use of absorbing material covered by perforated rigid panels, the overall absorption in such cases being an average of the amounts taking place through the holes and at the panel surface. In fact, sound absorption takes

place largely through the holes and the characteristics of such acoustic treatment therefore depend, among other factors, on their diameter and spacing. This technique works well in conventionally sized studios and control rooms, and indeed remains a very important method of sound control. Near to such absorbers, however, reflections from the hard panel can produce a 'edgy' or 'tinny' sound quality. In a vehicle, the walls and ceiling may be within about one metre of the sound control position, and this defect in sound quality can become very apparent. In current vehicle design, therefore, such hard surface treatment is confined as far as possible to areas where it will not cause direct specular reflections from known sound sources (the loudspeakers in particular). Parts of the ceiling, and wall areas below seated ear-height, represent convenient sites for this treatment. Surfaces within the vehicle from which troublesome specular reflection could occur are covered with material having sound absorbing characteristics which do not rely on 'averaging' between areas of high and low absorption. Conventional all-wool Wilton carpet (without underlay) has been found to be very suitable in this respect, and its use has the additional benefit of providing a visually attractive and hard-wearing finish to the walls of the vehicle. The ceiling area over and in front of the control position is also carpet covered, for specular reflection control.

3.19 Mechanical Services

Room acoustics can be effected by resonances from untreated metal ductwork, supply and extract grilles, plenums, bulkheads etc.

Internally unlined ducts can become a resonant cavity readily excited by music or speech generated in a studio or through loudspeakers. The solution detailed in section 1.3 (iv) b(i), requires the duct to be lined for a metre back from any grille or outlet with acoustically absorbent lining.

Externally untreated metal ductwork parallel to another externally untreated duct can cause flutter echoes and it is normal practice to externally clad one or both of the ducts with mineral wool treatment, acoustic tiles or carpet to eliminate the unwanted high frequency reflections.

Supply and extract grilles must not resonate when excited by music or speech generated within a studio or cubicle.

The grilles should be sufficiently self damped for none of the sections to readily vibrate. Section 1.3 (iv) b(ii) covers this point in detail.

Large voids which are used as plenums above false ceilings may require acoustic treatment to at least two adjacent wall surfaces to avoid resonances occurring within the void being audible in the studio below.

Bulkheads within any studio or control cubicle should be kept as small as possible with acoustic treatment applied to the underside to avoid resonances. (Sections 4.4 and 4.8 also cover this point).

3.20 Technical Equipment

The amount and variety of treatment required to achieve the acoustic conditions in a particular area will frequently leave little space on walls or ceilings for equipment and lighting fittings. A compromise can usually be arrived at with careful liaison with the project architect and the acoustics consultant at the design stage when account will be taken of the acoustic response of the equipment to be installed.

The acoustic layouts of technical areas are generally based on a modular system of absorbers and close liaison on the positioning of equipment bays, sockets and electrical fittings as well as the overall sizes of pattresses can result in a more satisfactory appearance to the studio or cubicle.

Equipment bays, control desks, tape machine trolleys, technical pattresses, dados and other items of technical equipment can produce unwanted acoustic reflections or resonances in control cubicles. The problems of unwanted acoustic reflections and siting of equipment are covered in section 4.6. In some instances it is possible to treat a reflective surface e.g. a dado, with carpet. Other items such as pattresses should be sited below or away from critical areas or heights.

Resonances can be controlled by the application of suitable damping compounds to

any metal panel which is likely to resonate. Hollow tubes should be damped by filling with suitable material e.g., dry sand. The damping compound must be non combustible.

3.21 Electrical Services

Much of the foregoing comments and recommendations outlined in the previous section 3.20 on Technical Services is applicable to Electrical Services in studios and control cubicles. Electrical equipment, trunking, power cabinets and pattresses all require siting carefully to avoid acoustic reflections and in some cases require acoustic damping to avoid resonances.

Particular care must be taken with the selection of any light fittings for studios or technical areas to ensure that they do not resonate (see also sections 1.8 and 4.8).

Anglepoise lamp fittings are often used to support microphones in self-drive studios. The four springs on the anglepoise lamp fitting resonate and consequently require damping either with rubber inserts or sleeves.

3.22 Ancillary Accommodation

Whilst the main emphasis of this 'Guide' has been devoted primarily to the acoustic consideration of studios and technical areas, there are a number of other rooms or enclosures within a broadcasting complex whose acoustic environment warrants closer examination.

The main areas are:-

(i) Newsrooms

The newsroom is generally one of the main centres of activity in a broadcasting centre. Filled with people, telephones, typewriters and teleprinters the newsroom can be classified as a potentially noisy area. Acoustic treatment therefore is required to reduce the build up of noise from the various sources. All available wall, floor and ceiling areas must be treated with absorbent materials.

The ceiling is generally the most useful surface available to the acoustician as the walls are often partially glazed and the floor surface screened by desks. Noise absorbers (see section 3.8 (vi)) or acoustic tile ceilings constructed with the tiles in a vertical grid pattern provide the most efficient system of absorption as both increase the actual overall absorbing surface area of the ceiling by a significant amount. Where the above systems cannot be used either on the grounds of spacial considerations or cost, a traditional flat acoustic tile ceiling has to suffice. The tile used in this case should be selected to provide the maximum possible absorption and cover the whole ceiling area. It should also be borne in mind that the lower the ceiling height the more efficient the acoustic tiles become at reducing the overall noise level within a room.

Wall treatments with acoustic panels are generally confined to areas between windows and other wall surfaces above table-top height where equipment or display boards are not required. It must be reiterated that the minimum acoustic treatment in any area is to two adjacent walls plus either the floor or ceiling. Otherwise flutter echoes will occur between the untreated surfaces which will make the situation worse and probably unacceptable acoustically (see also section 3.4).

All floor surfaces should be carpeted with provision being made in some cases for hard wear areas under desks being protected with mats. (See also section 3.13).

Drapes, soft furnishings and upholstered chairs will all provide absorption and help reduce the overall noise level.

Teleprinters and other noise producing equipment installed within a newsroom must have localised acoustic absorption around the equipment or be sited within an acoustically treated recess or enclosure.

Typewriters should be provided with rubber mats.

(ii) Open Plan Offices

Open plan offices, like newsrooms, require as much acoustic absorption as is feasible but even then and with voice levels lowered, confidential privacy is only just possible. Staff regularly requiring to discuss confidential matters should be sited in separate offices enclosed by full height

partitions whereas those requiring only occasional privacy should be provided with a fully partitioned room or 'refuge' within the open plan area to be used for the specific occasions.

The main surfaces available for acoustic treatment are as described for newsrooms in section 3.22 (i). Reductions in noise levels can also be achieved by the use of localised absorption e.g. acoustic wall panels, absorbent screens or room dividers placed close to the occupants.

Other means of improving the acoustics in open plan offices are by the careful orientation of desk layouts, ensuring that speech from one occupant is not directed towards another occupant, and by the use of distance and zoning to separate noise producing activities from areas requiring quiet. This can also include the careful positioning of any staff with loud and penetrating voices.

Loud telephone bells and amplified telephones must be avoided and any noisy office equipment should be sited within an acoustically treated recess or enclosure or, if the above is not possible, surrounded by localised absorption.

(iii) Conference Rooms

Conference rooms generally require only a nominal amount of acoustic treatment, but it is none the less important that it be provided. The design of any treatment (which includes curtains) must take into account the recommendations laid down in sections 3.1 and 3.4 otherwise flutter echoes will occur. These would be disturbing in a conference room, causing the sibilance in speech to be prolonged.

(iv) Canteens and Restaurants

The acoustic requirements for BBC canteens or restaurants are very similar to those recommended for newsrooms in section 3.22(i). Acoustic absorption is required to reduce the overall noise level of speech, movement of customers and the clatter of crockery and cutlery. Here again the ceiling is the most effective surface to treat acoustically. Acoustic tile ceilings should be suspended as low as possible over the whole restaurant area using tiles with high absorption coefficients.
The floor should be carpeted and acoustic panels should be applied to any bare wall surfaces above table top height.

Drapes, soft furnishings and upholstered chairs will all provide absorption and help reduce the overall noise level.

(v) Reception Areas

Reception areas are generally the focal point for any visitor to a broadcasting centre and the acoustics of such areas should be considered as part of the overall aesthetic design. BBC local radio stations in particular monitor the output of the station on loudspeakers sited in the reception and if the area is too live the programmes will become distorted. This situation is sometimes made worse when an untreated staircase rises direct from the reception area and the stairwell behaves as an echo chamber.

Acoustic absorption and soft furnishings should be provided in the reception area and to any area leading directly off it.

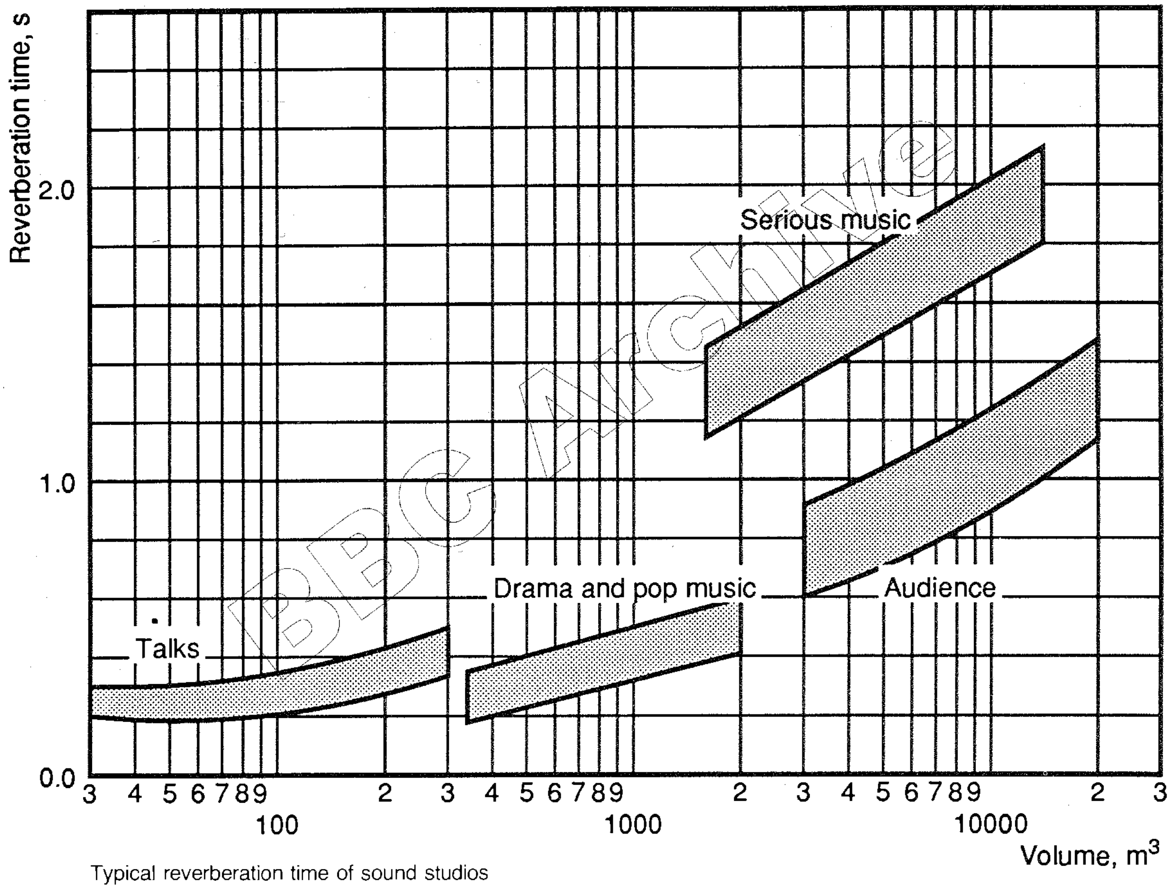
(vi) Workshops

Three basic categories of workshops exist in BBC premises which require acoustic consideration. These are mechanical, scenic and carpentry workshops, all of which include machinery or equipment which can generate high noise levels.

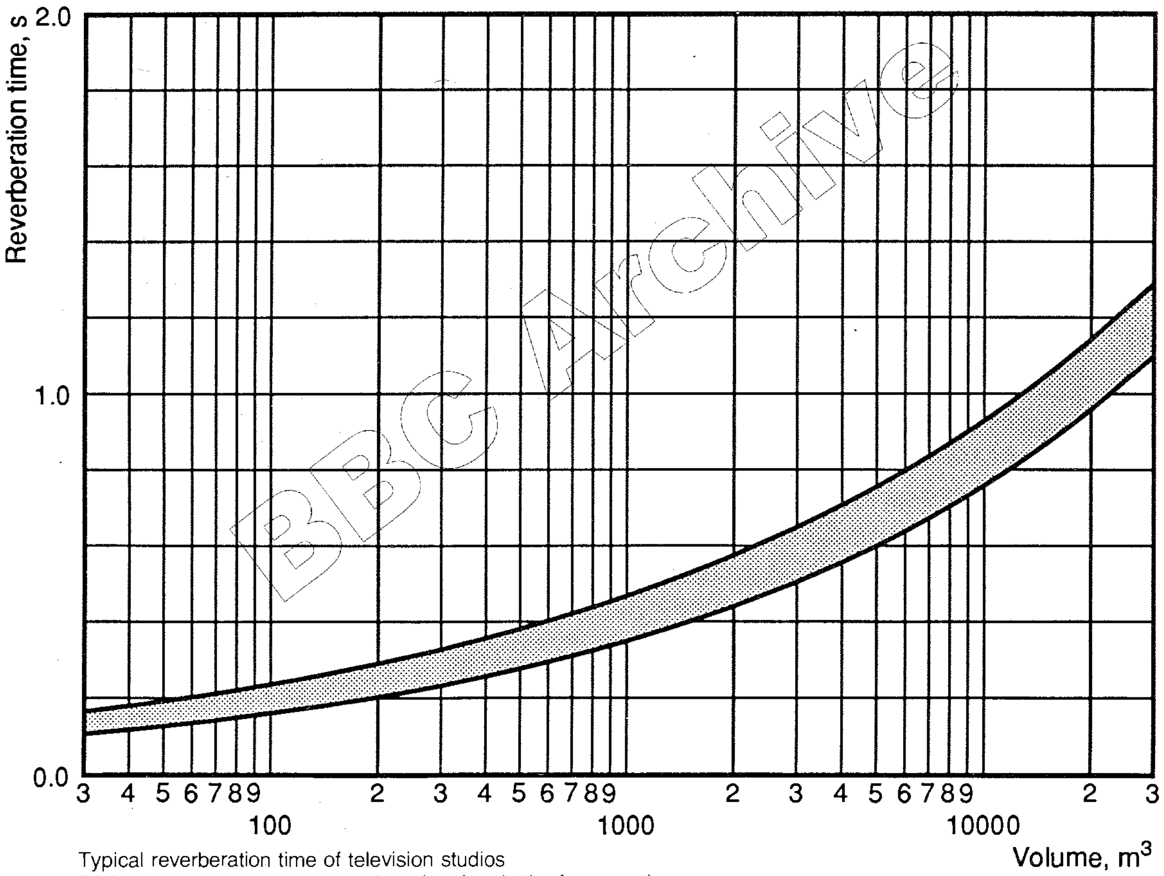
Whilst very little can be done acoustically to reduce the direct sound for any operative working near noise generating machinery, the provision of acoustic treatment on the ceiling and walls will reduce the overall noise level of any workshop. Functional absorbers or noise absorbers (see section 3.8 (vi)) should be suspended as low as possible over the whole ceiling area. The walls should be treated with mineral wool panels covered with an easily cleanable surface. Weldmesh protection is recommended for wall treatment to prevent damage to the treatment by materials being leant against it.

It must be borne in mind that the above measures will only reduce the overall noise level within a workshop and any operative working in close proximity to a noisy machine for any length of time must wear ear

defenders if the noise levels come within the statutory control range.

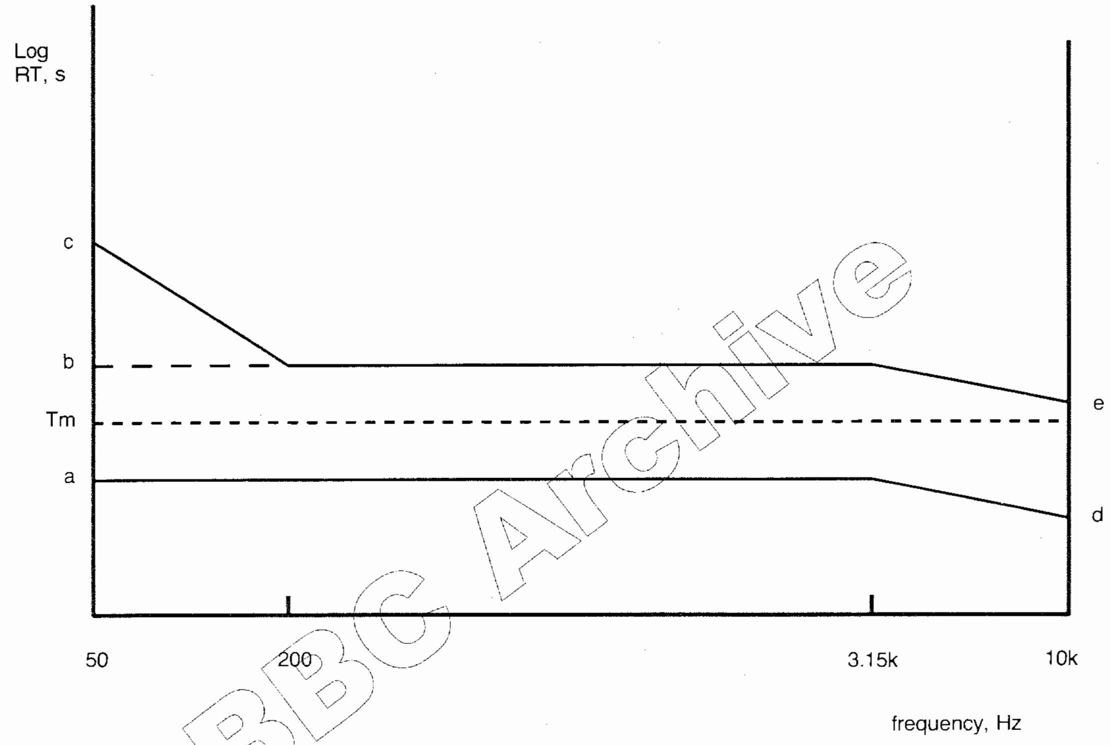


Typical reverberation time of sound studios



Typical reverberation time of television studios
(Values represent average reverberation time in the frequency)
(range 250-4000 Hz., based on preferred BBC studios)

Figure 34 Recommended Reverberation Times for Sound Studios and Television Studios



Tolerances for reverberation time

Type of area	Tm(s)(1)	a(2)	b(2)	c(2)	d(2)	e(2)
Talks studios and their control rooms	0.2	0.8	1.2	2.5	0.6	1.0
Other sound control room	0.2	0.8	1.2	1.2	0.6	1.0
Large music studio	1.6	0.9	1.1	1.1	0.8	1.1
Large TV studio	0.8	0.8	1.1	1.2	0.6	1.0

(1) This value is an example only. For typical ranges of values refer to figure 34.
(2) These numbers are multiples of the average value, Tm. They are not reverberation times in seconds.

Figure 35 Typical Values for Reverberation Time and Tolerances

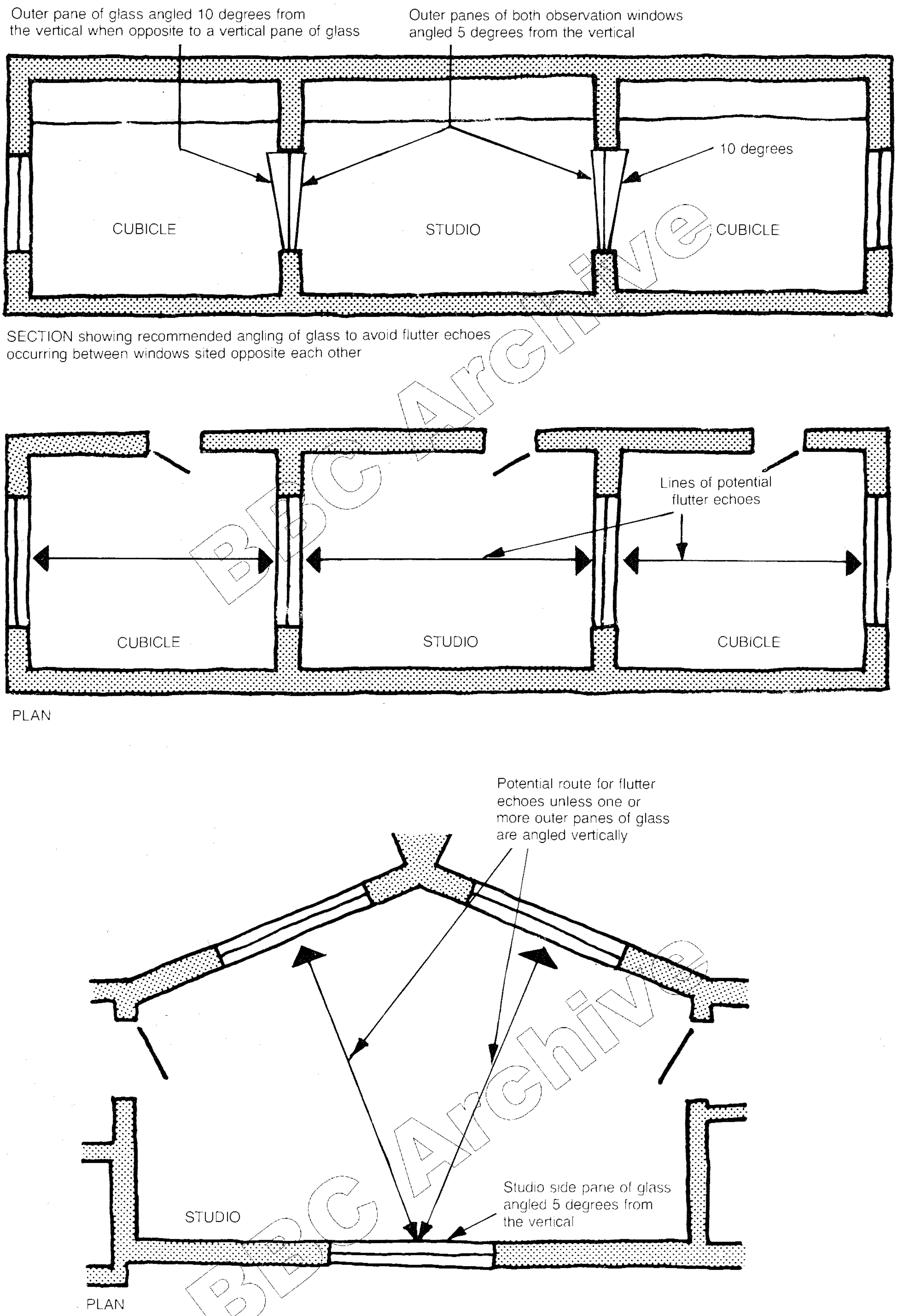


Figure 36 Typical Plans and Section showing Principles of Angled Windows to avoid Flutter Echoes

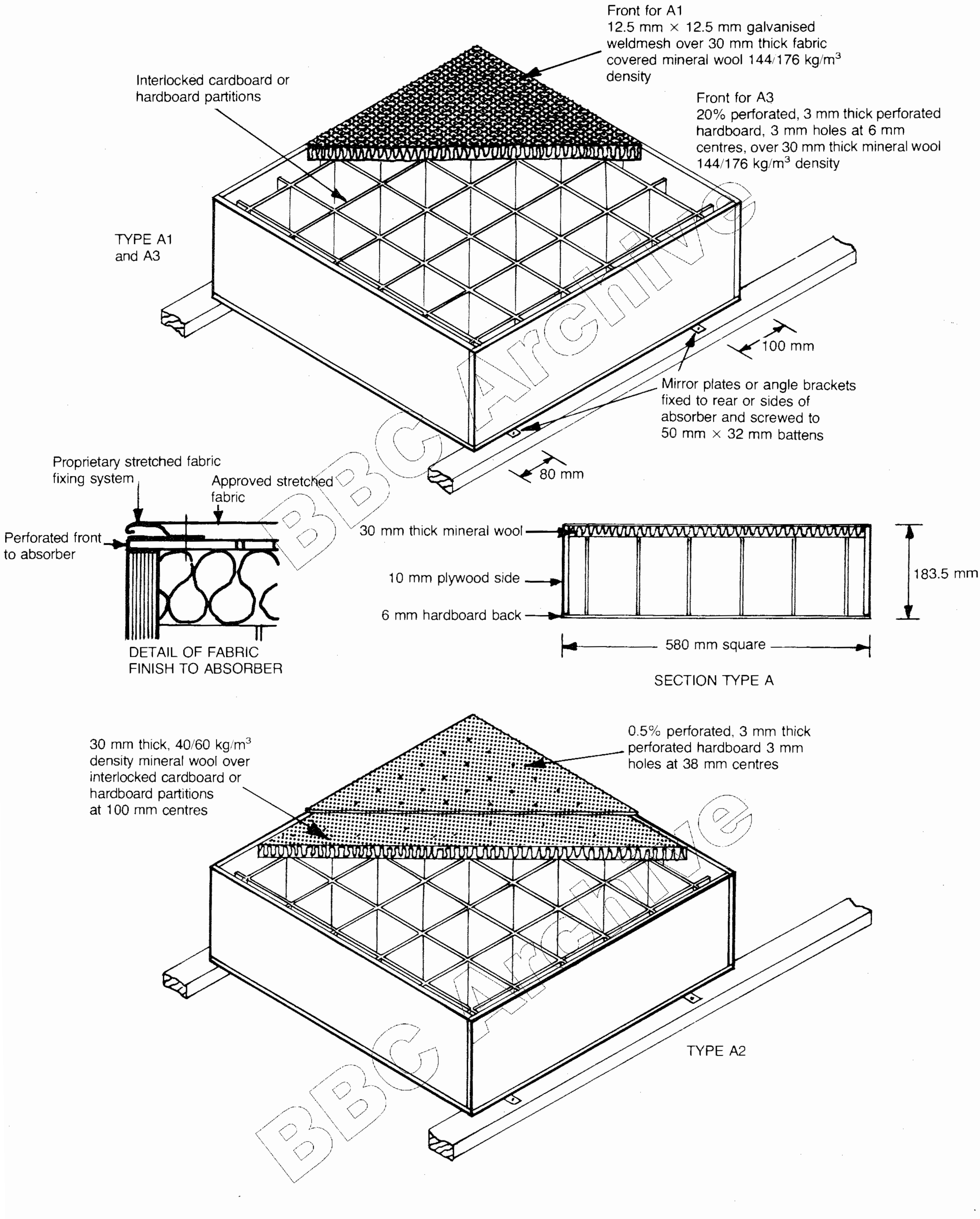


Figure 37 Modular Absorbers Types A1, A2 and A3

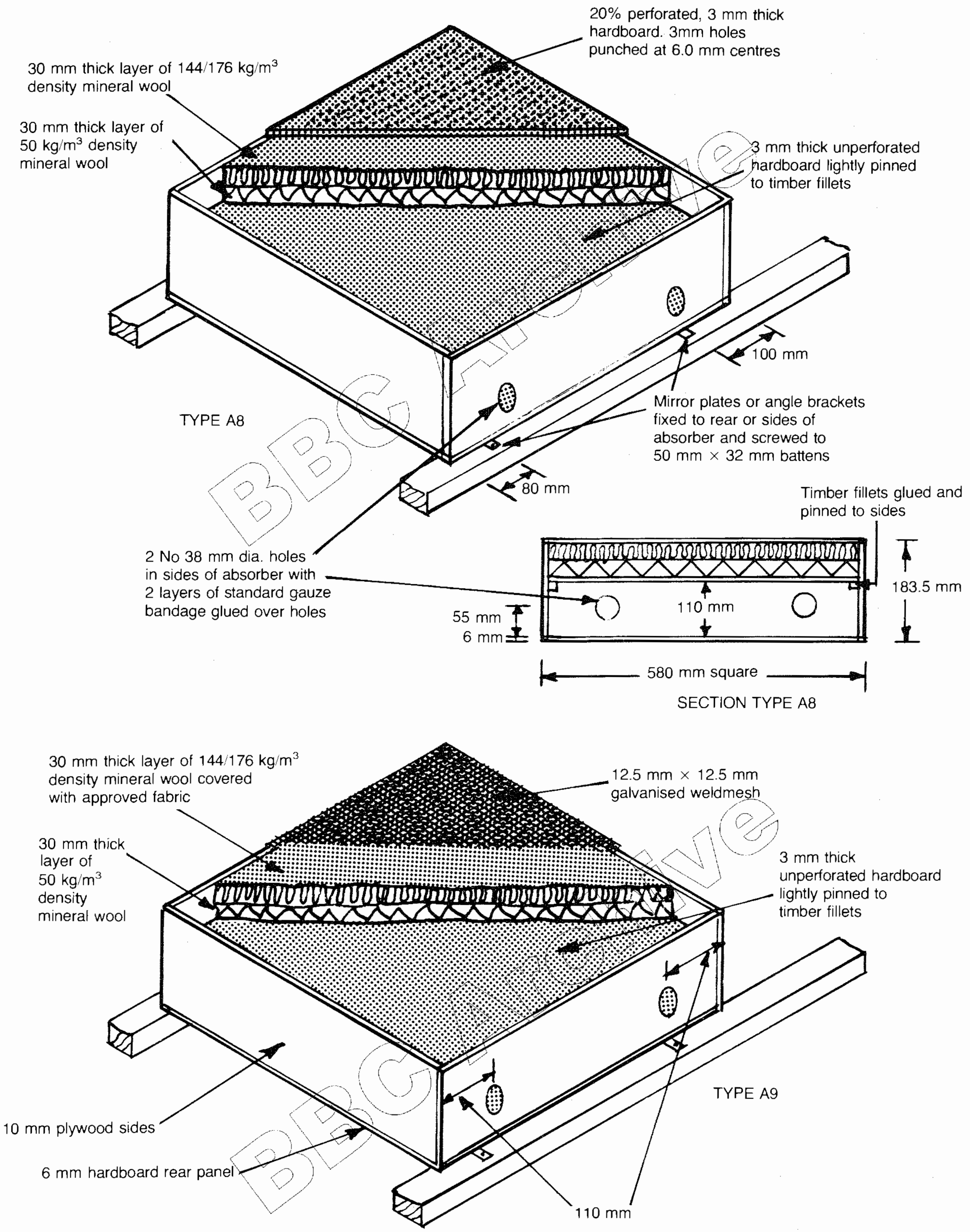


Figure 38 Modular Absorbers Types A8 and A9

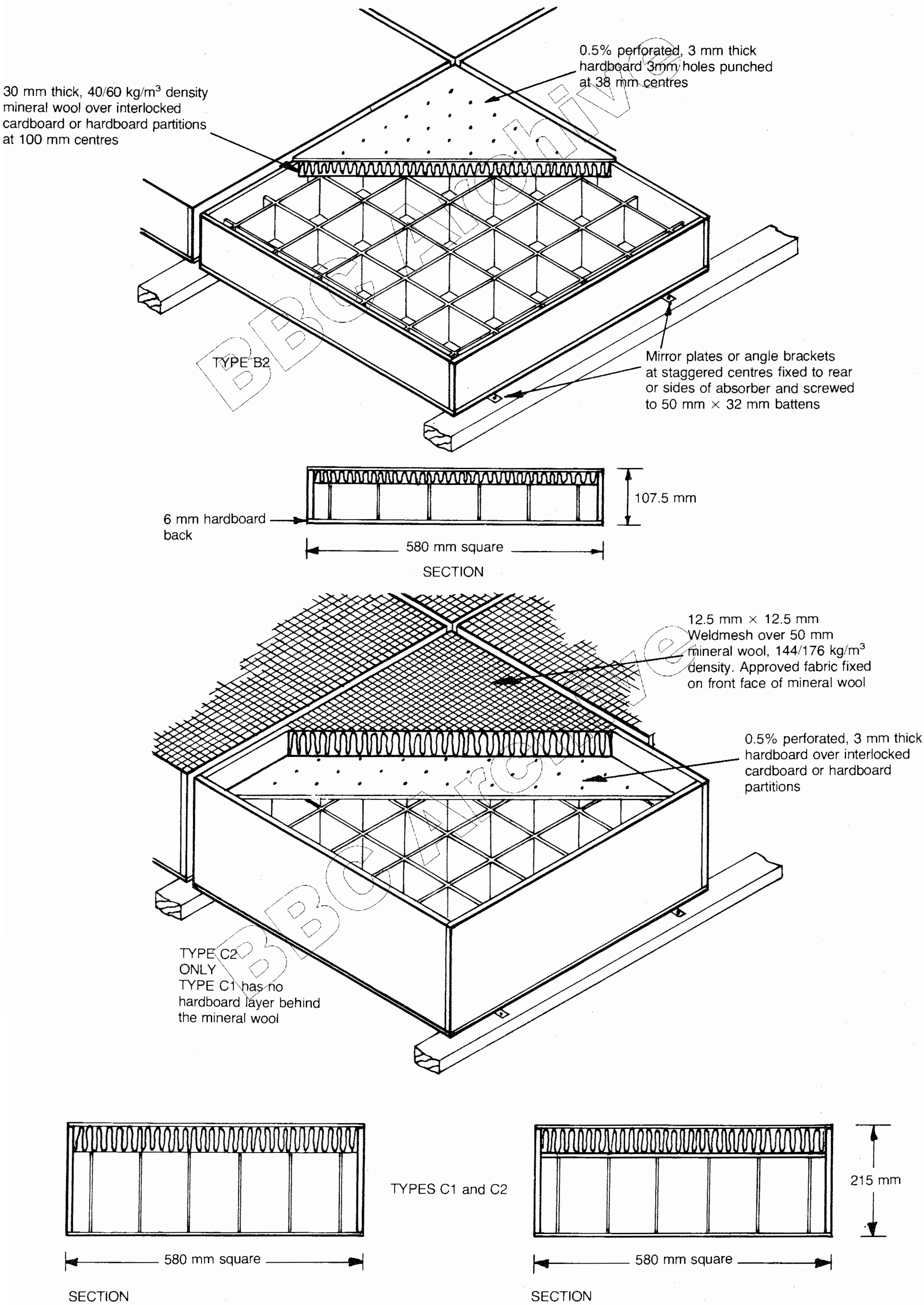


Figure 39 Modular Absorbers Types B and C

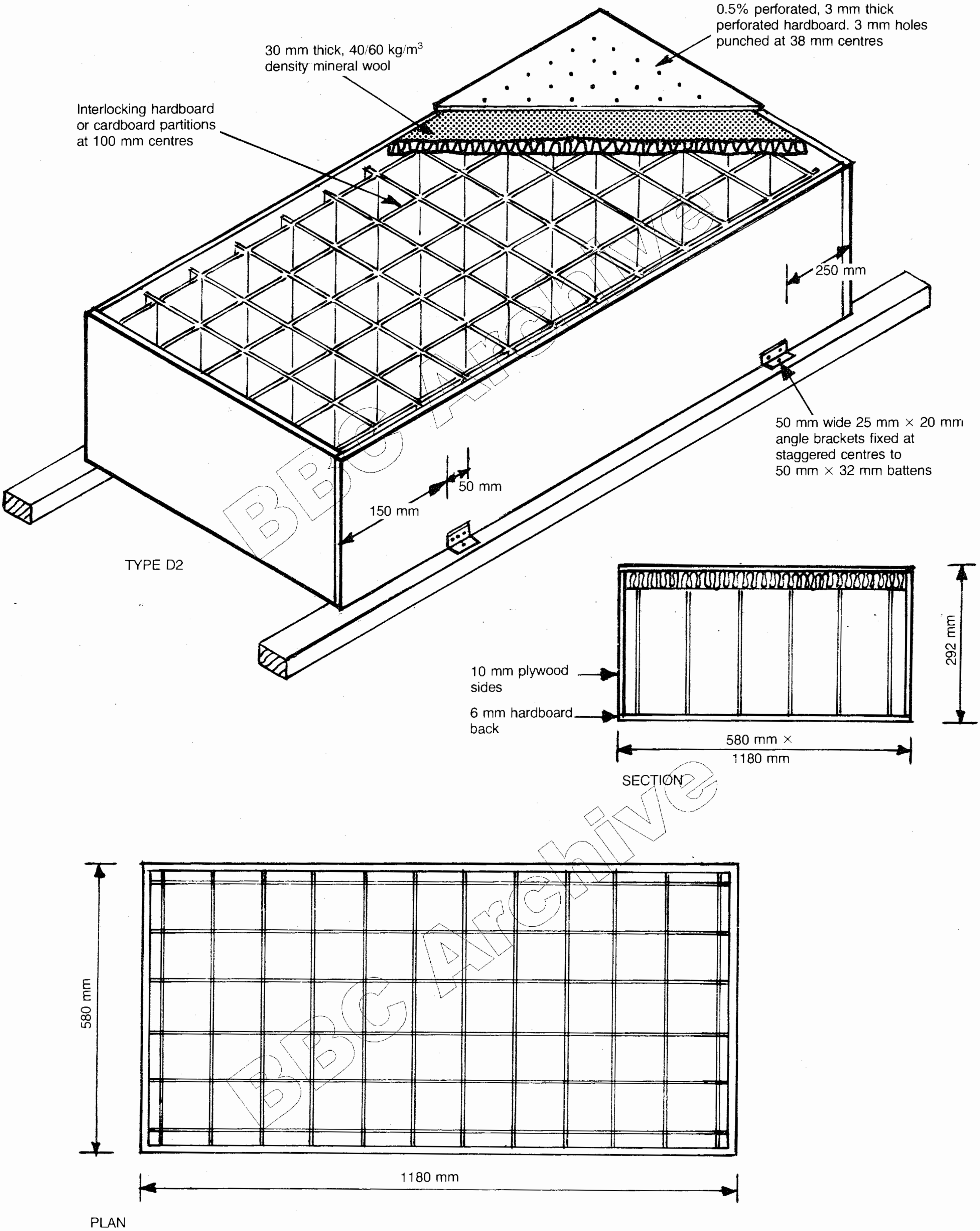
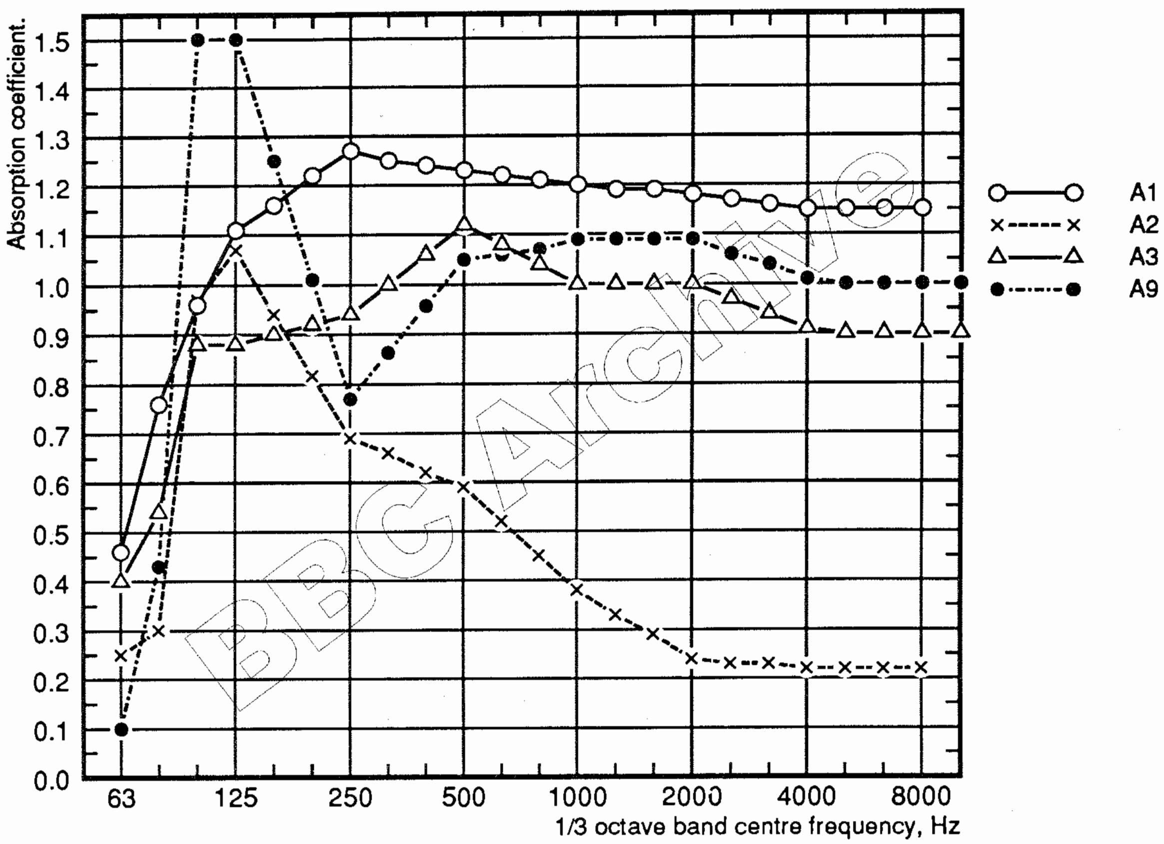
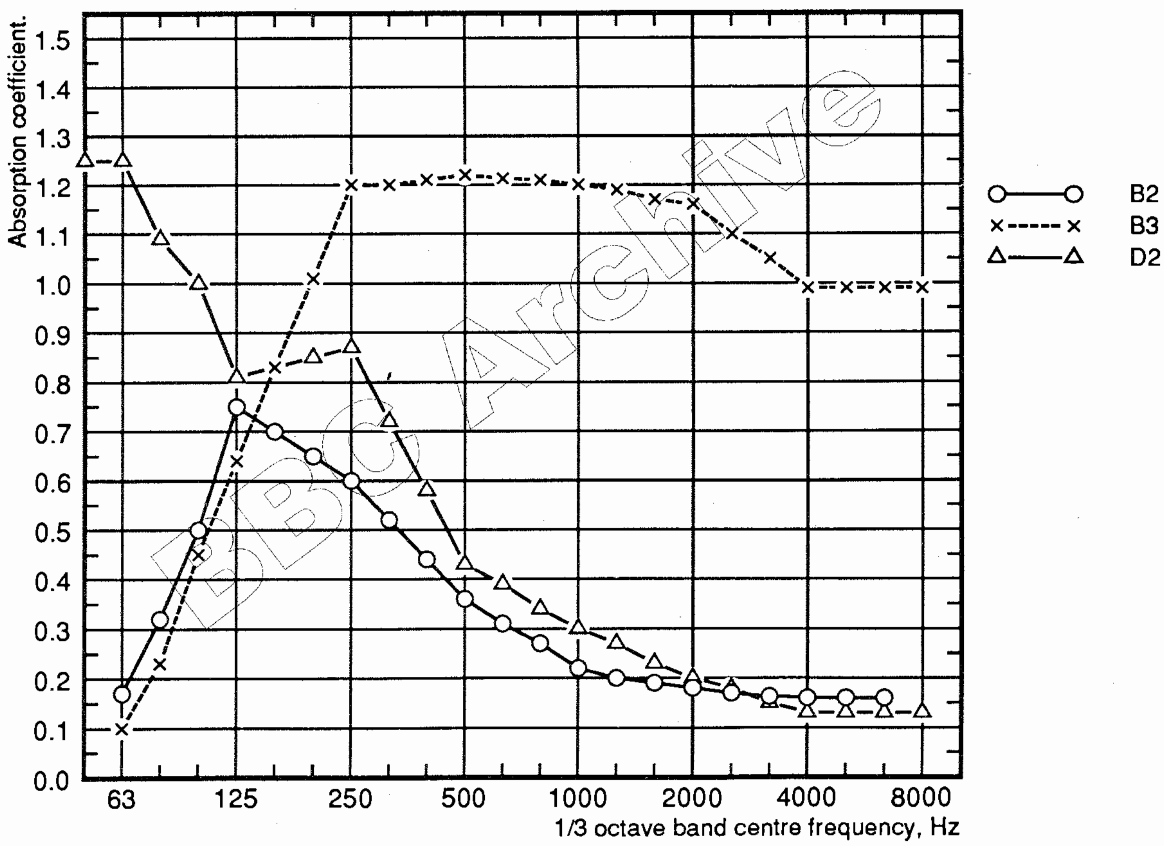


Figure 40 Modular Absorber Type D2

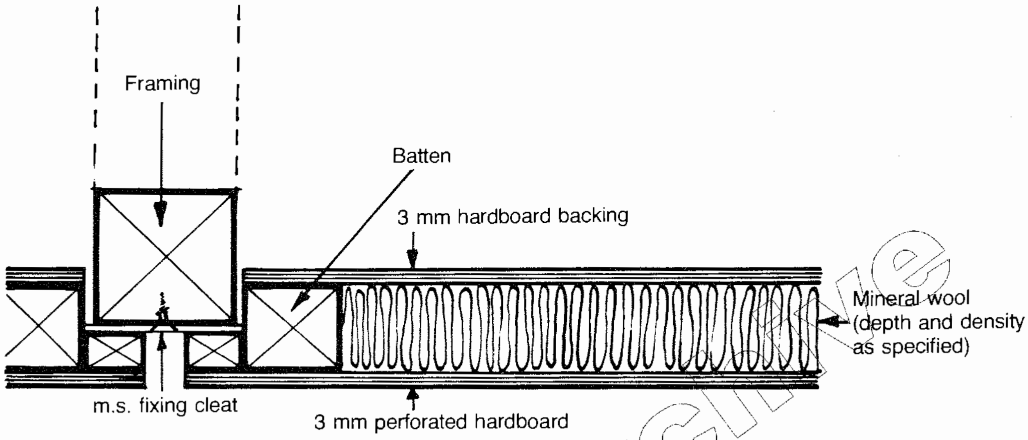


Typical absorption coefficients of 'A' size modular absorbers

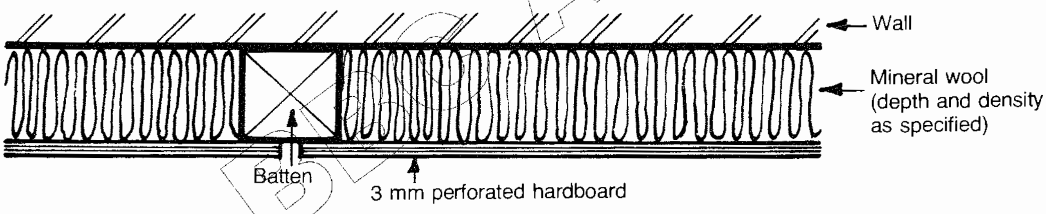


Typical absorption coefficients of 'B' and 'D' size modular absorbers

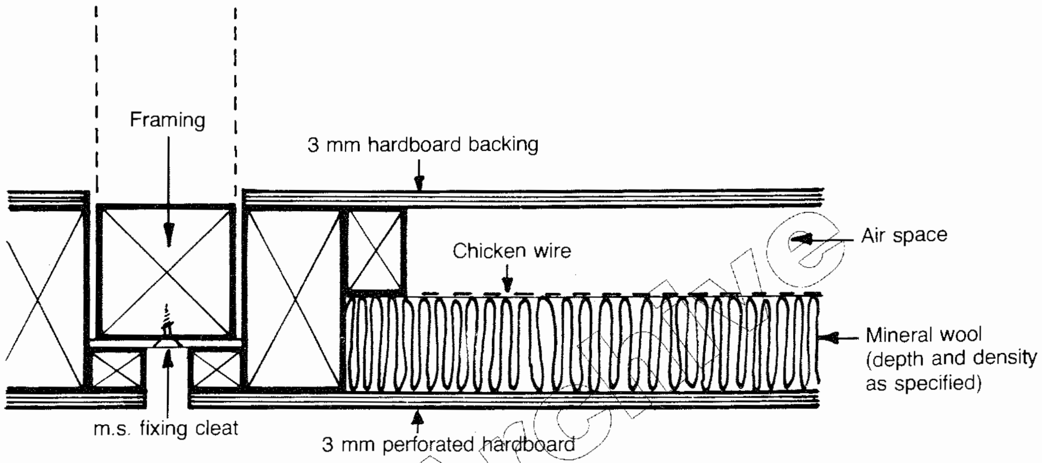
Figure 41 Typical Absorption coefficients for modular absorbers



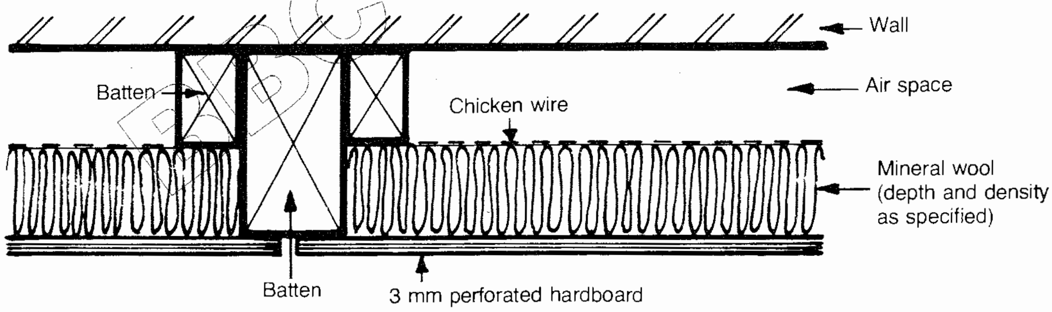
SHALLOW POROUS ABSORBER MOUNTED ON FRAMING



SHALLOW POROUS ABSORBER MOUNTED DIRECT ONTO WALL



POROUS ABSORBER OVER AIR SPACE MOUNTED ON FRAMING



POROUS ABSORBER OVER AIR SPACE MOUNTED DIRECT ONTO WALL

Figure 42 Porous Absorbers with perforated hardboard cover

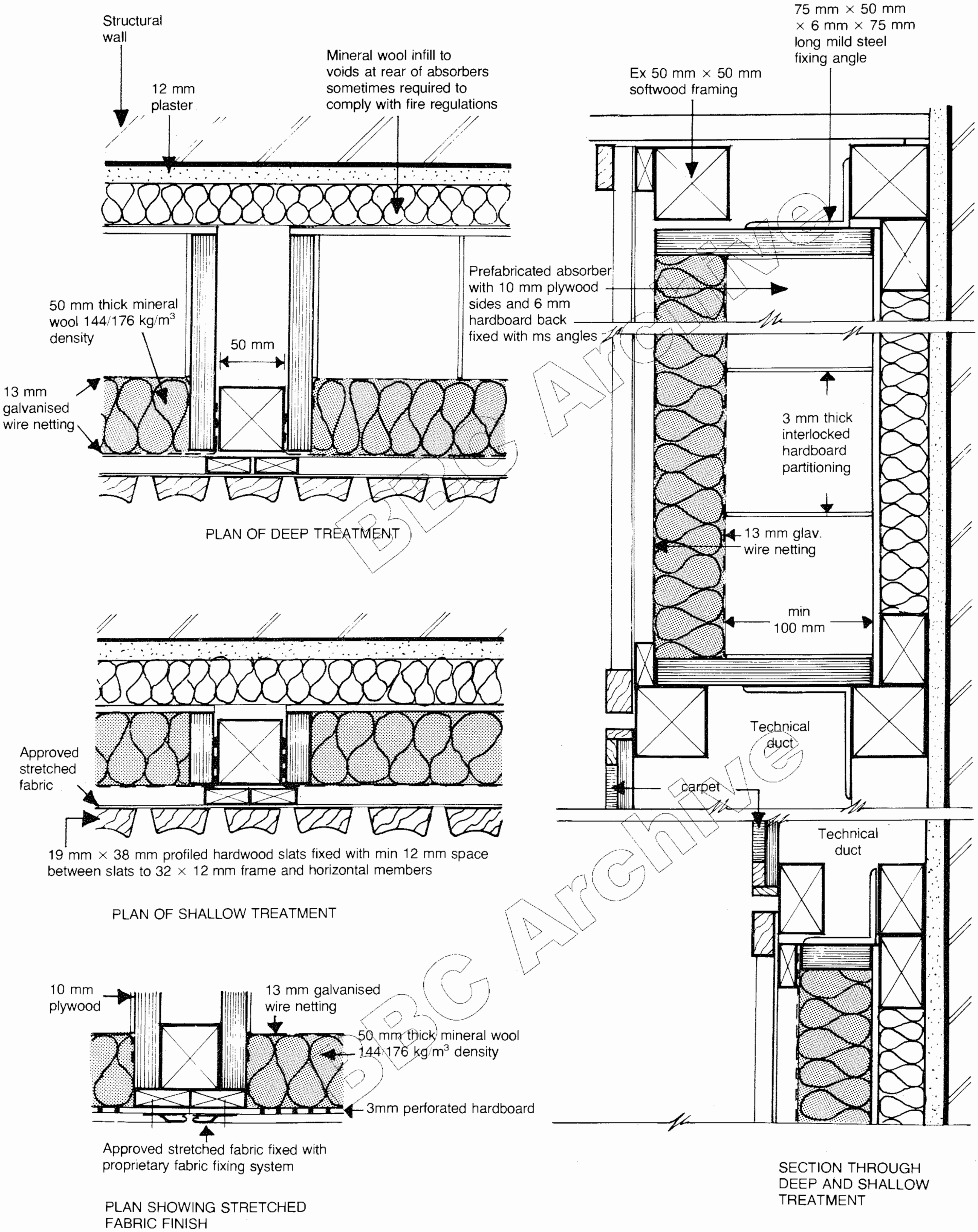


Figure 43 Prefabricated Wideband Porous Absorbers

Note: All timber should be treated to meet the necessary fire standards required for broadcasting buildings

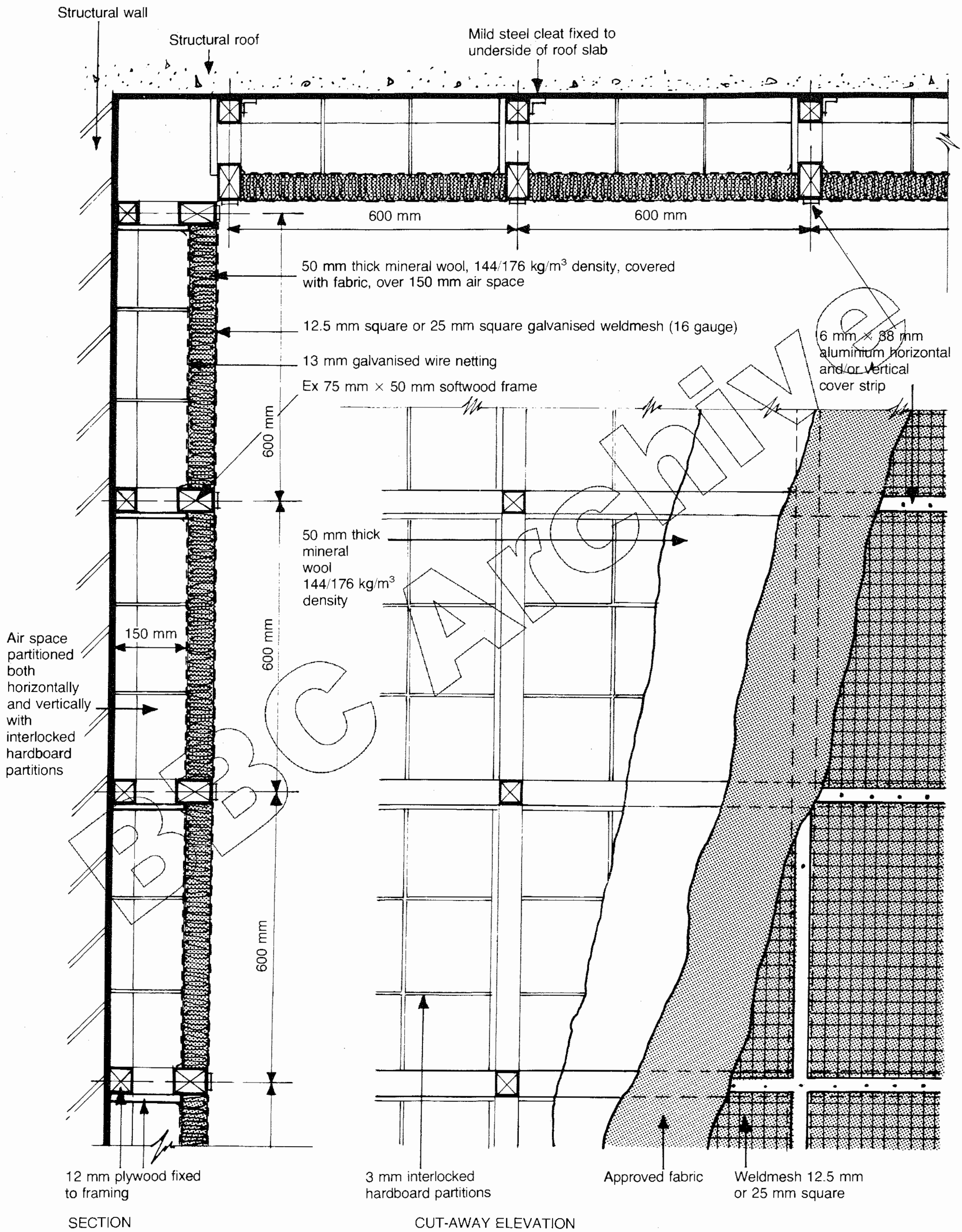


Figure 44 Typical details of Acoustic Treatment in Television Studios

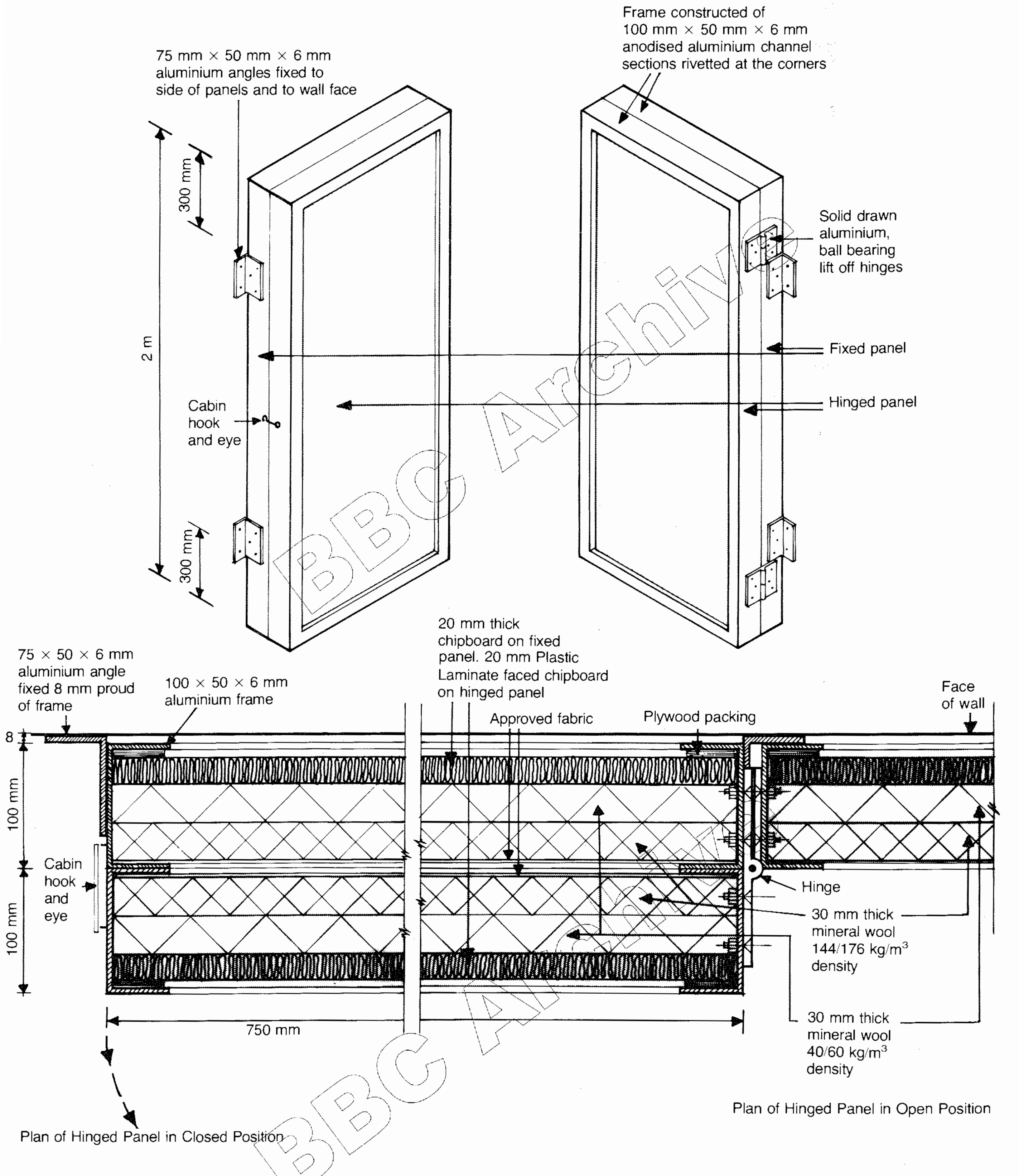
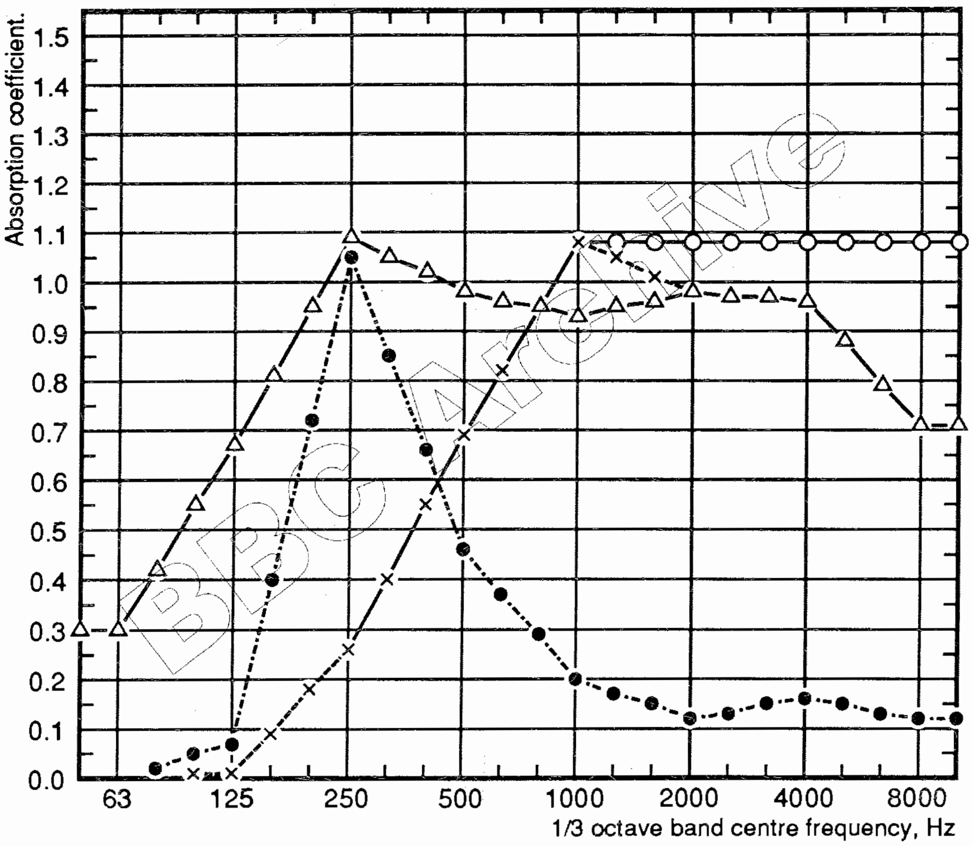


Figure 45 Typical Details of Variable Hinged Panel Absorbers



Typical absorption coefficients of high-density mineral wool (~150 kg/m^3)

O———O	25 mm thick over hard surface
×-------×	25 mm thick over hard surface, with 25% open-area cover
Δ———Δ	as above, but over 175 mm airspace
●·-·-·-·●	25 mm thick with 0.5% open-area cover

Figure 46 Typical Absorption Coefficients for Porous Absorbers

SECTION 4 GUIDELINES ON SOUND CONTROL ROOM LAYOUTS

ILLUSTRATIONS

4.1 Introduction

These guidelines apply to both Radio control rooms (often called control cubicles) and sound control rooms for Television. Often greater acoustic compromises have to be made in television than in radio, because of the need to accommodate more bulky equipment such as monitor stacks; however the basic principles of acoustic design remain the same.

The aim of control room design is to provide a sound that is affected as little as possible by the room. In areas where stereo sound is dealt with, the monitoring environment should also give the operator good information on image positioning.

Unfortunately, control rooms contain acoustically reflective items such as control desks and observation windows, usually with a lot of additional technical equipment. These not only have undesirable acoustic qualities in themselves, but also restrict the places where acoustic treatment can be positioned on the walls. To get the best compromise in the acoustic design, it is especially important that the acoustics consultant is kept fully involved with the equipment layout, and that no constructional changes are made without consultation.

As a first principle, all equipment which does not need to be in a control room for operational reasons, should be sited in a separate apparatus or machine room. This gives more freedom in the acoustic design and removes sources of noise. It also removes sources of heat, so there can be smaller ventilation ducts and grilles, reducing another potential source of acoustic problems.

If noisy items cannot be taken outside the room altogether, they should if possible be put in an acoustically designed enclosure or cupboard. Such an enclosure will often require separate ventilation.

In any case, the positioning, enclosing, etc. of any potentially noisy items should be discussed with the acoustics consultant. Note that, as well as items which contain fans, any large mains transformers are liable to produce significant noise, and sometimes even small mains transformers can produce a surprisingly loud buzz, especially if mounted on a resonant backing.

Noisy equipment which must be accessible to operators (e.g., sound recording equipment) can usefully be put in a heavily acoustically treated alcove.

4.2 General Layout

For stereo monitoring, the basic feature of the layout is the triangle formed by the two loudspeakers and the operator. The first design essential is symmetry; i.e., the two speakers must be equidistant from the operator. Differences in distance cannot be compensated for by unbalancing the levels of the speakers, as this seriously mars the clarity of the image.

Ideally the triangle should be equilateral, with each side about 2.0 to 2.5m. In small rooms it is often necessary to reduce the front to back dimension. i.e., the speakers remain 2.0m to 2.5m apart but the operator is rather closer to them. This is especially the case where there is a producer's listening position behind the operator.

It is not essential that the room shape is symmetrical around the operator-loudspeakers triangle, and indeed there is some evidence that this is better avoided. However it is essential that the ceiling height is the same over both speakers.

4.3 Observation Windows (Figures 47 and 48)

Both operator and producer usually need good sightlines into a studio via an observation window. Windows, being flat, shiny, and usually quite large, give excellent acoustic reflections, and since for good sightlines they must be near the operator, they always cause some acoustic degradation.

An observation window behind loudspeakers should preferably be provided with a lined curtain, so that sound reflections can be reduced when vision is not needed.

From the acoustic point of view, observation windows should never be larger than the minimum strictly necessary. When a studio is in use, it is sometimes found that the window is partially obscured, in Radio by loudspeakers, and in Television by monitors or semi-permanent cycloramas. If this happens, it shows that the window could and should have been smaller.

Where the window is planned to be between the speakers, sightlines should be carefully drawn to check whether the speakers hide part of it - if so, this indicates that the window can be made narrower. Figures 47 and 48 shows how the sides of a window can be angled, and the acoustic treatment can be cut away, to give the best sightlines together with the minimum window area on the control room side.

For stereophonic monitoring there are two basic layouts: the window can be between the loudspeakers, or to one side of the operator. Both layouts have their advantages, and the choice is usually made on non-acoustic grounds.

Where there are several windows in a control room or studio, one or more of them will sometimes need to be angled in the vertical plane, or occasionally in the horizontal plane, to prevent a resonance between them known as a flutter echo. Only the pane nearest the inside of the room should angled. Usually either one window is angled by 10^{o}, or else two by 5^{o} each in opposite directions. This topic is covered in more detail in sections 2.8. and 3.4.

4.4 Doors

Doors to cubicles should never be sited between or adjacent to monitoring loudspeakers. Deep door alcoves on either the studio or cubicle side of a wall or lobby should also be avoided.

4.5 Loudspeakers Positioning and Mounting

Loudspeakers are influenced by their surroundings. Some loudspeakers (generally specialist large units used for music monitoring) are specifically designed to be set into a wall with their fronts flush with the wall surface, and when using these special design considerations apply. However the majority of monitoring loudspeakers, including all BBC designed loudspeakers at the time of writing, are intended to be used free-standing. Ideally these should not be positioned too near any wall or in a corner.

In practice however, space restrictions often force loudspeakers to be sited near a wall, in which case acoustic treatment must be applied to the wall surface to reduce sound reflections.

If layout restrictions force a monitoring loudspeaker near to a corner, space must be left on both wall surfaces for deep acoustic treatment (at least 200mm) in the corner.

Sound levels near loudspeakers will be significantly higher than in the rest of the room, so it is particularly important that the speakers are not near anything that can resonate, buzz, or rattle, e.g., a door, cupboard, ventilation grille, equipment rack, etc.

Where the design of the ventilation system is such that a bulkhead protrudes down from the ceiling, this should be at the back of the room; not over the speakers or to one side. Designs which provide a flat ceiling are preferred.

It is sometimes necessary to mount small loudspeakers on walls or on desktops. A loudspeaker mounted rigidly on a wall is likely to transfer sound into the next room by making the wall vibrate, so resilient mountings are necessary. This is the case even with small intercom loudspeakers. Loudspeakers mounted on a control desk, either directly or on brackets, will excite resonances within the desk, so again resilient mounting is advisable.

4.6 Reflections Affecting the Stereo Image

The stereo image will be particularly affected by reflections from the side between the loudspeaker and the operator. It is therefore necessary to have absorbent or diffusing acoustic treatment in this position. Equipment with vertical-fronted flat panels (e.g., equipment bays, dados, control panels) should not be placed at either side of the operator at seated head height. If there is an observation window at the side of the operator, it will give an unavoidable reflection, and so a curtain should be provided so that the reflection can be reduced when the window is not in use. There is no advantage in providing a symmetrical reflection on the other side of the room - this will merely make matters worse.

4.7 Control Desks

Because the control desk is near both the operator and the loudspeakers, special care

must be taken to ensure that it affects the sound as little as possible. So far as acoustics are concerned, wrap-round desk designs are best avoided, as they can give serious coloration of the sound. Vertical or near vertical panels at one or both sides will generally adversely affect the stereo image.

If a control desk has a large near-horizontal control surface, it is essential that the ceiling above it be absorbent or diffusing to avoid reflections between the two. Large flat light fittings should not be used in this position.

Metal desk panels must be well damped and firmly screwed down, particularly any at the rear where they will be near the loudspeakers. Tubular steel desk frames must also be damped, otherwise they can resonate strongly. The most effective method of damping hollow steel tubes is to fill them with dry sand.

4.8 Resonances Within the Room

Resonances colour the sound, and therefore must be prevented. They can be caused in a number of ways:

1. Between parallel flat surfaces ("flutter echoes") as noted above in connection with observation windows.

2. Within partially enclosed spaces such as alcoves.

3. By the vibration of solid items such as metal panels.

The first and second of these are normally dealt with as part of the overall acoustic design. However it is essential to ensure that no changes take place that introduce a flutter echo, e.g., the replacement of a modular absorber by an item of equipment with a flat vertical surface, opposite another reflecting surface. Alcoves must always be acoustically treated.

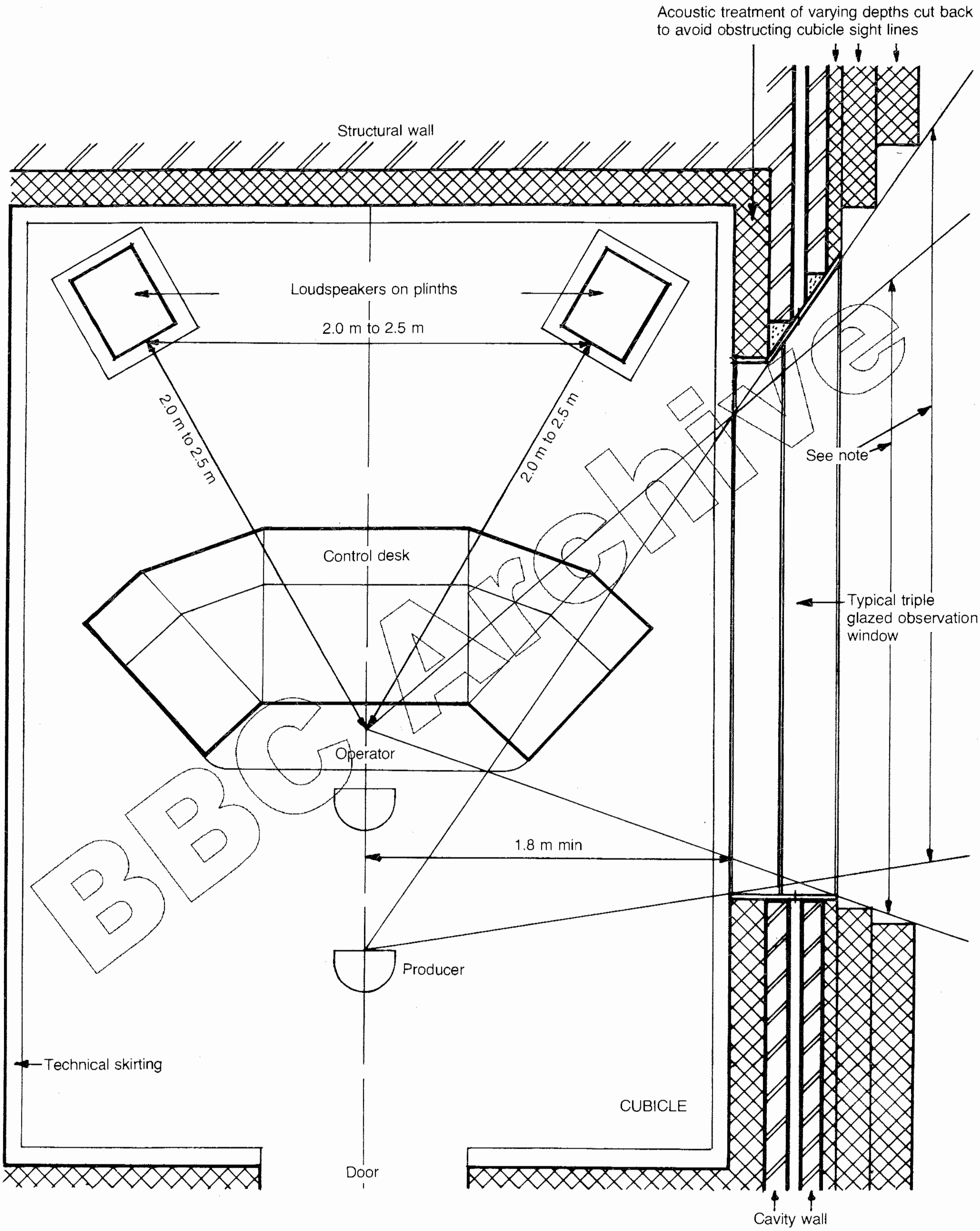
It is also essential to ensure that the plant and equipment in any control room does not resonate. Lighting is a frequent source of problems. Some high-efficiency reflectors contain numerous pieces of thin metal which give strong resonances. Spotlight reflectors or cowls sometimes ring, and it is preferable to use small spotlight fittings (sometimes called "bullet") rather than those with large reflectors. Square fluorescent fittings (600mm x 600mm) with prismatic or opal diffusers are usually satisfactory, if the diffusers are well clamped or damped with rubber around their edges. When windows are angled, visual reflections of lights can be a nuisance. To avoid this, flat lighting diffusers in troublesome positions can be replaced with metallised plastic honeycomb diffusers that direct the light downwards. This topic is covered in more detail in section 1.8.

4.9 Computer Access Floors

"Computer Floors" normally known as "access floors" (modular flooring systems with removable panels) are not normally acceptable in Radio control cubicles, as they generally resonate at low frequencies. They generally have to be accepted in Television sound control rooms, because of the large number of cables to be accommodated.

Great care should be taken when lifting these panels, particularly during the initial technical installation period. Damage can cause ill-fitting tiles to rock or the substructure to squeak with acoustic consequences.

So that worn areas of carpet can easily be replaced, and to give access to floor ducts, loose-laid tiles are sometimes used rather than carpet on underlay. This can usually be accommodated in the acoustic design provided that the consultant is warned in good time.



NOTE: Sight lines. Angles varied according to width of window and size of studio

Figure 47 Plan showing basic requirements for sight lines for stereophonic studios

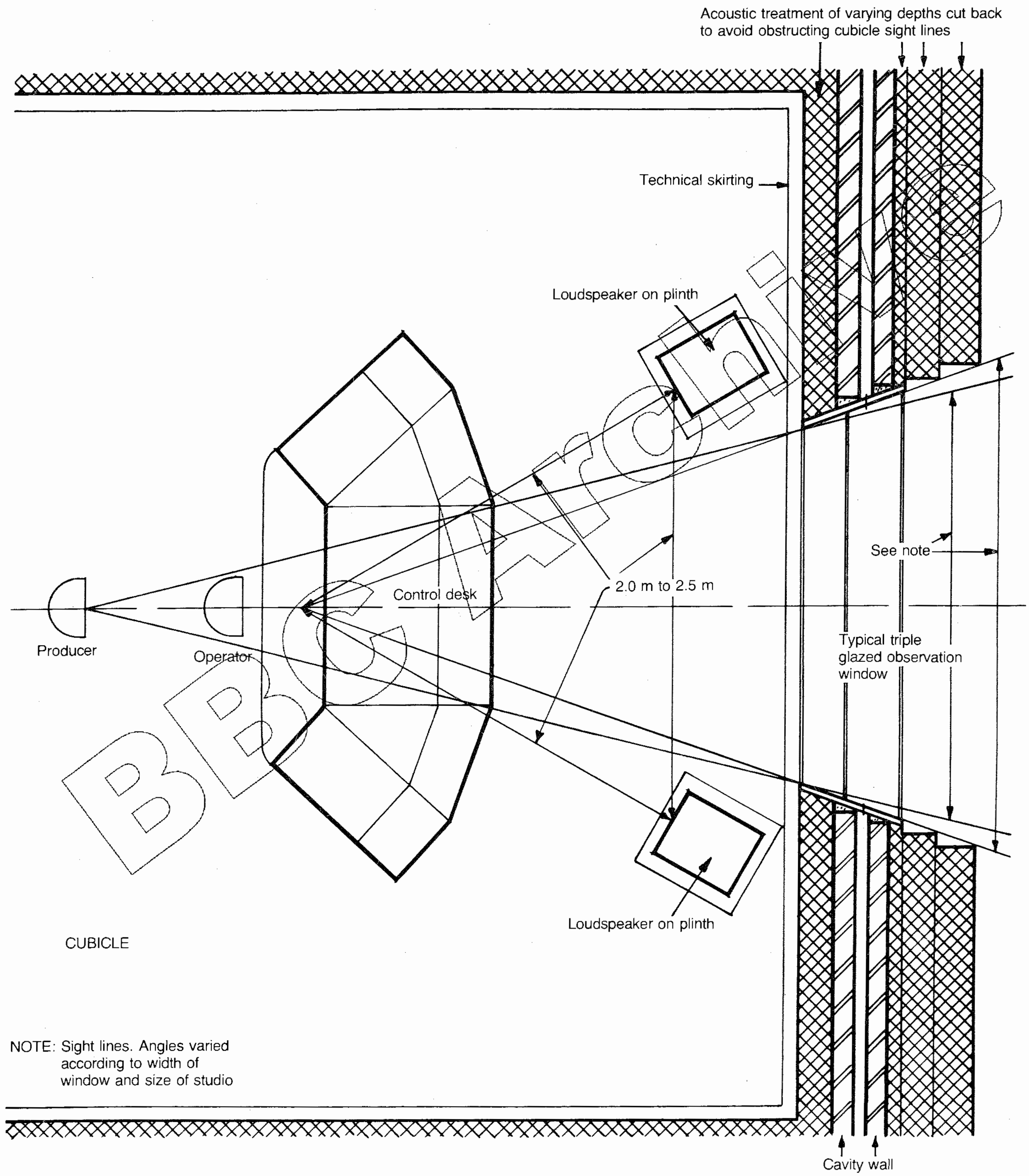


Figure 48 Plan showing basic requirements for sight lines for stereophonic studios

SECTION 5 THE ACOUSTIC EFFECT OF STUDIO FURNITURE

ILLUSTRATION

5.1 Introduction

Whilst certain items of furniture or fittings such as acoustic screens, tables, curtains and carpets are specified to produce particular effects it is important to remember that anything in the studio will, by its very presence, affect the overall acoustics in some way. Waste paper bins, filing cabinets and metal tape bins, which can all resonate, should all be sited outside studio areas.

Heavily upholstered seating in a studio can cause very significant absorption especially if the seating has foamed plastic filling. In some areas, such as concert halls, this can be used to advantage where, for example, tip-up audience seating is used which is specially designed to give similar absorption whether occupied or not. However, in studios which are designed to have a relatively reverberant acoustic, such as those used for chamber music, it is important that unintentional absorption is not introduced in the form of furniture. If soft upholstered chairs or settees are contemplated for use in such studios it is imperative that approval for their inclusion is obtained from the acoustics consultant and it may be necessary to obtain samples of the furniture for acoustic appraisal and measurement.

The foregoing comments apply in reverse to the use of metal cabinets or lockers in acoustically dead areas as these can provide unwanted reflections.

5.2 Acoustic Screens

Acoustic screens are used in BBC studios for two basic reasons; firstly to provide some degree of acoustic isolation or separation between two parts of a studio or secondly to modify the reverberation effects as picked up by a microphone. For the majority of situations a convenient arrangement is to use a group of screens each of which has an absorbent side and a reflective one; this enables local sound reflections to be readily modified to produce the acoustic condition required.

The older type of the acoustic screens used by the BBC were of relatively thin, lightweight construction, and frequently were provided with a large Perspex window which could be covered if necessary by a thin, hinged flap of absorbent material. These screens have generally been superseded as their acoustic properties are less significant than their psychological effects. The acoustic separation provided by this type of screen is limited by its lightweight construction (Mass Law) and the layer of absorbent material generally is too thin to provide very much sound absorption at low frequencies.

The current range of screens overcomes both of these inadequacies and is a good example of the application of the general principles of acoustic insulation and absorption described elsewhere in this book. Improved attenuation of sound is provided both by a heavy chipboard septum (faced with melamine on the "bright" side to provide enhanced reflections) and by the thick layer of high density mineral wool. The acoustic isolation is limited more by flanking sound paths around the screen, than by the attenuation of the screen itself.

The absorbent material consists of a 25mm layer of high density mineral wool backed by a 50mm layer of low density material. This combination of densities saves weight and cost relative to 75mm of high density absorbent and in addition the high density layer behaves partly as a damped membrane thus providing absorption at fairly low frequencies.

Early models for these screens used plastic foams for the absorbent material and were covered with an inherently flameproof fabric. However the use of plastic foams is now discouraged as it may be a source of toxic gases if subjected to fire. The current design of screen as already mentioned uses a mineral wool infill which has a tissue face bonded to it to prevent skin irritation caused by contact with the mineral wool and to reduce settling or sagging of the mineral wool.

The absorption of these screens is very high and therefore the feet are designed to allow very close stacking of them when they are not in use. Without this facility of being able to obscure the absorbent faces, the presence of a dozen screens (being stored rather than used) in a studio as large as 2000 m^3 will cause a serious reduction in the overall reverberation time.

A range of aluminium framed, fabric faced, standard screens exists but the versions in general use are 1 metre wide by 1 metre or 2 metres high. In certain situations where an acoustic tent is required, roof sections, manufactured similarly but with additional structural bracing, are used. Screens incorporating windows are also available.

The same form of absorbent panels may be applicable elsewhere where for example wall mounted panels are provided within a noisy news room to provide more efficient localised sound absorption than would be otherwise provided by a commercial telephone hood. This enables the operator to use a microphone of broadcast quality within the news room itself.

In the case of open plan office or newsroom areas, where room dividers are required to provide some form of acoustic separation, some commercial screens are acceptable.

5.3 Acoustic Tables (Figure 49)

In broadcasting studios, contributors to programmes are frequently seated at a table with the microphone either suspended above the table or alternatively fitted to a short stand resting on the table itself. If the table surface reflects sound then an unfavourable acoustic effect can occur due to the sound of the contributor's voice being picked up not only by the direct path from his or her mouth to the microphone, but also after reflection from the table top a fraction of a second later. This can distort the quality of the sound that is broadcast.

Attempts to reduce this effect by the provision of thick table cloths have proved unsuccessful, as a covering of 3mm thick provides no significant absorption in the frequency range where these colorations of speech quality occur.

The solution adopted for use in talks or discussion studios, where these tables are usually situated, has been to construct a special table with a perforated top to reduce the percentage of sound that is reflected. A variety of perforated materials have been tested but the current combination of materials is shown in figure 49. The materials illustrated provide a reasonable degree of acoustic transparency whilst at the same time providing a table top on which it is possible to write on a script or on a piece of paper.

The surface layer of fireproofed fabric will gradually suffer a build up of dirt over the years which will impair its acoustic properties. It is essential therefore to renew the fabric every few years.

5.4 Rostra

In music studios where it is essential for the various sections of the orchestra to see and be seen by the conductor, rostra are often used. They can however give rise to acoustic problems in two ways.

Firstly, they may themselves produce noise by creaking or rocking and, if their construction is 'boxy' and undamped they can produce 'thumps' and 'booms' from footsteps or other movements.

Secondly, they may act as low frequency absorbers if they are not suitably constructed and, in particular, they are liable to degrade the tone and quality of low frequency stringed instruments, such as cellos or double bases, if these stand on the rostra.

The introduction of rostra into a studio not previously equipped with them can also give rise to other acoustic problems such as high frequency reflections or flutter echoes between the vertical surfaces of the rostra and any nearby plain wall surface. This problem can be overcome by adjustments to the acoustic treatment as approved by the acoustic consultant.

The rostra must be constructed with a rigid framework, and an upper layer of 25mm veneered blockboard has proved satisfactory as a floor surface. The fronts, backs and sides of the rostra should be covered with 6mm plywood. Approved damping materials must be applied to the internal surfaces of the rostra to dampen the resonances caused by impact noises.

Temporary or mobile rostra are often less satisfactory than permanent constructions and the types manufactured in the form of simple wooden boxes are seldom adequate. However certain proprietary folding systems have proved to be satisfactory.

5.5 Scenery and Cycloramas

The selection of scenery flats for use in the construction of a set for a particular production in a television studio is generally based on the availability of materials but certain types of materials have been found to be particularly suited to the representation of some surfaces; for example, the surface irregularity of brickwork or stonework can be well simulated by flats made from fibreglass and resin whose surface can be moulded.

On the majority of occasions, the acoustic qualities of the materials used in the construction of a scenery flat are of considerable importance and should be taken into account when the set is being designed. This is particularly true in the case of orchestral and operatic productions.

Acoustic information concerning the absorptive or reflective properties of materials used for scenery flats is almost non-existent and selection of materials has, therefore, relied on the past experience of those involved.

In order to provide objective data on which selection could be based, measurements of the acoustic properties of typical materials used in the construction of flats were made by the BBC Research Department and are the subject of a report issued by them.

From their findings it is apparent that a woven fabric has a low acoustic reflection factor. Its suitability for the construction of sets is however limited largely to cycloramas and back drops.

When the fabric is of painted canvas stretched over a wooden framework, the reflection coefficient increases at middle and high frequencies to a value similar to that of plywood-backed materials. The flats made from plywood or hardboard form a large class of fairly efficient reflecting materials whose behaviour at the high frequencies may be affected slightly by the surface finish.

The most efficient acoustic reflectors of all the flats tested proved to be the fibreglass ones and particularly because of their hard surface finish, the aluminium faced plywood ones.

With the exception of draped fabrics the absorption of flats is small, but draping of heavy fabrics within a television studio will provide efficient absorption.

If a pair of reflecting surfaces are constructed opposite and parallel to each other a flutter echo may occur between the surfaces. This effect must be avoided at all times particularly in small interview studios where the presence of flats or reflective cycloramas will mask the acoustic treatment on the walls to such an extent that the studio acoustic becomes excessively live.

The problem can be overcome by the splaying of one wall or by the provision of an absorbing surface to one of the opposite walls.

Concave arrangements constructed in acoustically reflective materials will cause focusing of sound. If concave arrays are required for visual reasons the sets must be manufactured from an acoustically transparent or non-reflective material.

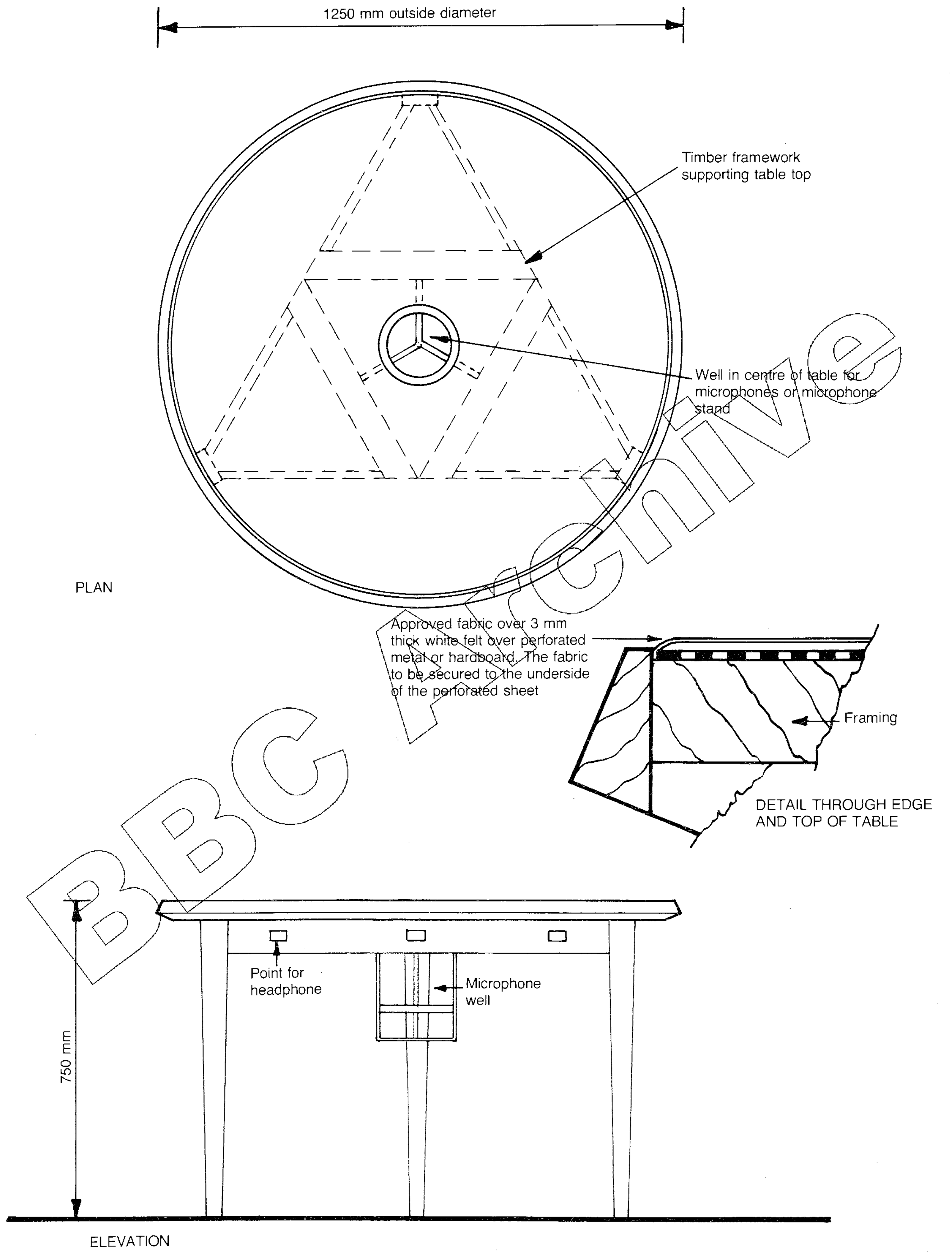


Figure 49 Typical Acoustic table

Section 6

TIMING OF ACOUSTIC TESTS

6.1 Introduction

Much has been said in the preceding chapters about achieving acoustic standards but nothing has been written about the timing of acoustic tests to ascertain whether such standards have been met. In the BBC it is normal practice to carry out acoustic tests at the following stages.

6.2 Prior to any Project Commencement

This falls into 2 categories:-

(i) Where the project comprises a completely new studio complex, a full airborne and vibration survey should be carried out to ascertain the extent of airborne noise and vibration levels on the new site. These provide essential design data which should be used in the planning and layout of any new project.

As stated in Section 1.1 all airborne noise should be measured in a one-third octave analysis to provide information which can be related to building product data.

(ii) Where the project is for the refurbishment of existing premises a full survey, again in one-third octaves, should be carried out to ascertain that the noise and vibration levels, sound insulation and reverberation times of technical areas meet the required standard; or if not, what remedial measures are required to meet the standards or user requirements. Measurements should still be made even if the refurbishment only involves replacement of technical equipment.

6.3 During Construction

Preliminary sound insulation tests are usually carried out as soon as the Studio observation windows, doors and ventilation duct installations are complete and prior to any acoustic treatment being installed. These particular tests are aimed at checking that the building structure is intact or alternatively identifying any acoustic problems such as holes around observation windows, doors, ventilation ducts etc. which could cause expensive remedial action if the faults were found after the areas had been finished and fully equipped.

All technical and electrical cable ducts must be fully pugged for these tests.

In large studios it is often desirable to carry out reverberation time measurements in the empty studio shell. Such tests are required to check that the structure and other building elements, such as ventilation ductwork or droppers are behaving as predicted and not providing unexpected absorption. Further reverberation tests may be necessary in large orchestral studios at certain stages of the installation of the acoustic treatment and finishes.

6.4 Final Tests

A full acoustic survey of the Acoustics, Sound Insulation and Noise levels should be carried out at the completion of all building work and with the technical equipment in position.

The main purpose of these tests is to confirm that the necessary acoustic standards, as specified in the original project requirements, have been met or whether modifications or remedial work will be required.

Section 7

GLOSSARY OF ACOUSTIC TERMS

Acoustics:

1. The science of sound.

2. Of a room, auditorium or a studio. Those factors that determine its character with respect to the quality of sound received by the occupants or a microphone.

Ambient Noise:

Encompassing sound (at a given place), being usually a composite of sounds from many sources near and far.

Anechoic Room:

Room whose boundaries absorb substantially all the sound incident thereon, thereby affording free-field conditions.

Audibility Threshold:

Modal value of the thresholds of hearing for a large number of listeners between 18 and 30 years of age with otologically normal ears.

Background Noise:

Total of interference from all sources in a system used for the production, transmission, detection, measurement, or recording of a signal.

Damping:

(1) The action of frictional or dissipative forces on a dynamic system causing the system to lose energy and reduce the amplitude of movement.

(2) Removal of echoes and reverberation by the use of sound absorbing materials.

Decibel:

The commonly used unit used for the comparison of the powers of levels of sound. Abbreviation dB.

Diffuse field:

Sound field which in a given region has statistically uniform energy density, and for which the directions of propagation at any point are randomly distributed.

Echo:

Sound wave that has been reflected and arrives with such a magnitude and time interval after the direct sound as to be distinguishable as a repetition of it.

Note 1: In common usage the term is limited to reflection distinguishable by the ear.

Note 2: In broadcasting parlance and in the labelling of equipment and controls the word ECHO has been used to mean artificial reverberation.

Flutter echo:

Rapid but nearly even succession of echoes originating from the same sound source.

Flanking transmission:

Transmission of sound from a source room to an adjacent receiving room but not via the common partition.

Note: The term may also be used to describe any indirect path of sound transmission.

Helmholtz resonator:

A resonator consisting of a cavity in a rigid structure communicating by a narrow neck or slit to the outside air.

Note: The frequency of resonance is determined by the mass of air in the neck resonating in conjunction with the compliance of the air in the cavity.

Hertz:

The unit of frequency measurement, representing cycles per second. Abbreviation Hz.

Honk:

An unwanted, audible coloration usually caused by a mid-frequency resonance.

Isolation:

Resistance to the transmission of sound by materials and structures.

Loudness:

That attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from soft to loud.

Masking:

The process by which the threshold of audibility of one sound is raised by the presence of another (masking) sound.

Multiple echo:

A succession of distinct echoes from a single source.

Noise:

Sound which is undesired by the recipient. Undesired electrical disturbances in a transmission channel or device may also be termed 'noise' in which case the qualification 'electrical' should be included unless it is self-evident.

Noise emission level:

The dBA level measured at a specified distance and direction from a noise source, in an open environment above a specified type of surface. Generally follows the recommendation of a national or industry standard.

Noise rating curves:

An agreed set of empirical curves relating octave band sound pressure level to the centre frequency of the octave bands, each of which is characterized by a 'noise rating' (NR), which is numerically equal to the sound pressure level at the intersection with the ordinate at 1000 Hz. The 'noise rating' of a given noise is found by plotting the octave band spectrum on the same diagram and selecting the highest noise-rating curve which the spectrum just touches.

Octave:

1. A pitch interval of 2:1.
2. The tone whose frequency is twice that of the given tone.
3. The interval of an octave, together with the tones included in that interval.

Pascal, Pa:

A unit of pressure corresponding to a force of 1 newton acting uniformly upon an area of 1 square metre. Hence 1 Pa = 1 N/m^2.

Pink noise:

Noise whose power spectral density is inversely proportional to frequency.

Resonance:

State of a system in forced oscillation such that any change, however small, in the frequency of excitation results in a decrease in a response of the system.

Note: 1. The quantity that is the measure of response should be indicated; for example velocity resonance.

Note: 2. Musicians frequently use the word RESONANCE to mean a desired reverberation characteristic of a hall or studio.

Resonant frequency:

A frequency at which resonance occurs in a system.

Reverberation:

The sound that persists in an enclosed space, as a result of repeated reflection or scattering, after the source of the sound has stopped.

Reverberation time:

Of an enclosure, for sound of a given frequency; the period of time required for the mean square sound pressure in the enclosure, initially in a steady state, to decrease, after the source is stopped, to one-millionth of its initial value, i.e. by 60 dB. The unit is the second.

Sabine:

A measure of sound absorption of a surface. One metric sabine is equivalent to 1 sq. metre of perfectly absorptive surface.

Sound:

Movement of particles in an elastic medium about an equilibrium position.

Sound absorption:

1. Attenuation of a sound wave on passing through a medium or striking a surface.

2. The property possessed by materials, objects or media of absorbing sound energy by conversion to heat.

Sound absorption coefficient:

The ratio of absorbed to incident energy for specified conditions and at a specified frequency. It can be expressed as the ratio between the equivalent surface area of an ideal absorber (i.e. one which absorbs all of the incident sound energy) and the physical area of the real absorber. It can apparently exceed unity under some circumstances.

Sound insulation:

1. Means taken to reduce the transmission of sound, usually by an enclosure.

2. Of a partition. The property that opposes the transmission of sound from one side to the other.

Sound Intensity:

The rate of sound energy transmission per unit area in a specified direction.

Sound level:

Logarithm of the ratio of a given sound pressure, obtained with a standard frequency weighting and with standard exponentially-weighted time-averaging, to the reference sound pressure of 20μ Pa. Sound level in decibels is 20 times the logarithm to the base ten of that ratio.

Sound level meter:

An electronic instrument for measuring the level of sound in accordance with an accepted national or international standard.

It consists of a microphone, amplifier and indicating instrument having a declared performance in respect of directivity, frequency response, rectification characteristics and ballistic response.

Sound power:

The total sound energy radiated by a source per unit time.

Sound power level:

The sound power level of a source, in decibels, is equal to 10 times the logarithm to the base 10 of the ratio of the sound power of the source to the reference sound power. In case of doubt, the reference sound power should be explicitly stated.

Sound pressure:

At a point in a sound field. The alternating component of the pressure at the point. The unit is the Pascal (Pa).

Sound pressure level:

The sound pressure level of a sound, in decibels, is equal to 20 times the logarithm to the base 10 of the ratio of the r.m.s. sound pressure to the reference sound pressure. Unless otherwise stated the reference level is 20μ Pa.

Sound pressure level difference:

In decibels, the difference in space and time average sound pressure levels produced in two rooms by one or more sound sources in one of them.

Sound reduction index:

Ratio of the sound energy emitted by an acoustical material or structure to the energy incident upon the opposite side. The unit is the decibel (dB). In American usage, this term is called 'sound transmission loss'.

Sound transmission:

The transfer of sound energy from one point in a medium to another point, or from one medium to another medium.

Sound transmission class, STC

A single number rating for describing sound transmission loss of a wall or partition.

Sound wave:

A disturbance whereby energy is transmitted in a medium by virtue of the inertial, elastic and other dynamic properties of the medium. Usually the passage of a wave involves only temporary departure of the state of the medium from its equilibrium state.

Stereophony:

A process designed to produce the illusion of a spatial distribution of sound sources, by the use of two or more channels of information.

Wavelength:

The distance in the direction of propagation of a periodic wave between points of comparable amplitude with a phase difference of one period. Equals the ratio of the speed of sound in the medium to the fundamental frequency.

Weighting network:

An electrical filter in a sound-level meter which approximates under defined conditions the frequency response of the human ear. The 'A' weighting network is most commonly used in room acoustics, hence the unit dB(A).

White noise:

Noise whose power spectral density is essentially independent of frequency.

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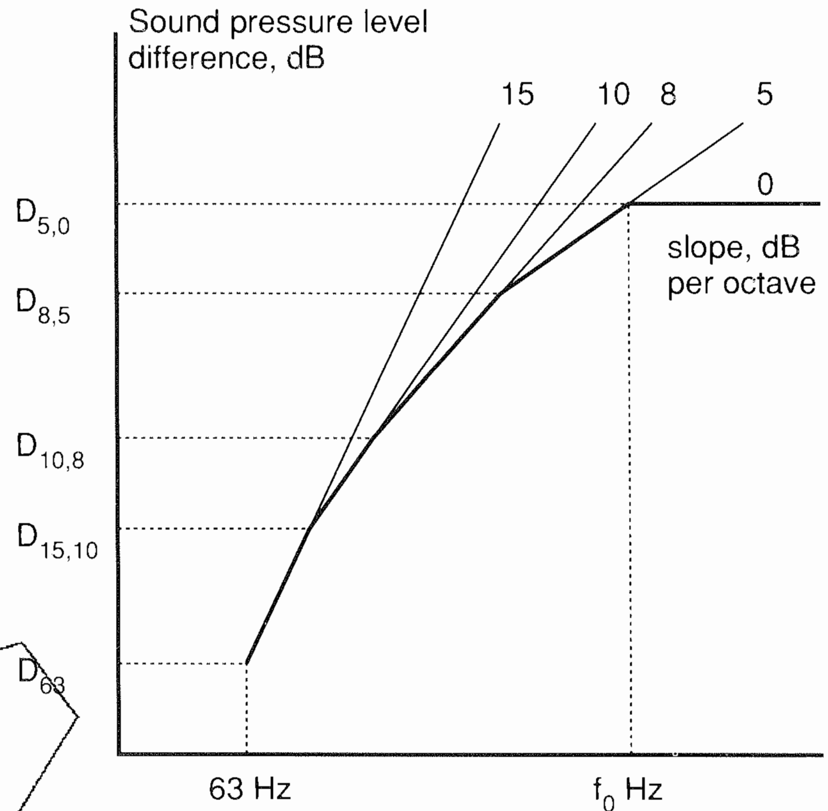
NOTES

1. For protection of the internal area from external sound. The requirements for areas needing exterior noise control may be different.
2. For protection of the programme areas only. Additional insulation may be required for protection of other areas from programme sound, if required.
3. The figures given are for complete protection. In most cases, 5dB may be subtracted from the specified insulations to give conditions which have been found to be generally acceptable.
4. Figures based on 'Light'/'Classical' music. 'Pop' music producer's offices may have levels up to 17 dB higher at 125 Hz.



D_{63}	$D_{15,10}$
$D_{10,8}$	$D_{8,5}$
$D_{5,0}$	$f_0/100$

RADIO																														
Studio, Orchestral music	51 66 66 82 87 10																													
Studio, Recital and small music	56 71 71 87 92 10	48 78 83 87 90 8																												
Studio, Pop	66 81 81 84 97 10	71 86 86 89 102 10	66 81 81 84 97 10																											
Studio, Pop continuity	56 71 71 87 92 10	49 76 83 87 90 8	71 86 86 89 102 10	49 58 67 74 82 10																										
Studio, Talks / continuity / narrator's	56 71 71 87 92 10	48 78 83 87 90 8	71 86 86 89 102 10	49 58 67 74 82 10	34 52 60 65 69 6																									
Studio, Drama	61 76 76 92 97 10	53 83 88 92 95 8	76 91 91 94 107 10	54 63 72 79 87 10	39 57 65 70 74 6	37 52 62 65 70 6																								
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Control cubicle, Recital and small music	56 71 71 87 92 10	48 78 83 87 90 8	71 86 86 89 102 10	49 58 67 74 82 10	34 61 63 71 74 8	38 68 68 76 79 8	57 57 82 86 89 8	33 63 63 71 74 8																						
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Building exterior, via roof (Note 1)	41 41 46 58 71 16	46 46 51 63 76 16	41 41 46 58 71 16	46 46 51 63 76 16	46 46 51 63 76 16	51 51 56 68 81 16	41 41 46 58 71 16	46 46 51 63 76 16	41 41 46 58 71 16	46 46 51 63 76 16	46 46 51 63 76 16	46 46 51 63 76 16	46 46 51 63 76 16	46 46 51 63 76 16	46 46 51 63 76 16	46 46 51 63 76 16	46 46 51 63 76 16	46 46 51 63 76 16	24 24 34 42 52 10	16 16 26 31 41 8	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0							
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Private office (Note 2)	37 37 37 37 64 25	42 42 42 42 69 25	37 37 37 37 64 25	42 42 42 42 69 25	42 42 42 42 69 25	47 47 47 47 70 16	37 37 37 37 64 25	42 42 42 42 69 25	37 37 37 37 64 25	42 42 42 42 69 25	42 42 42 42 69 25	42 42 42 42 69 25	42 42 42 42 69 25	42 42 42 42 69 25	42 42 42 42 69 25	42 42 42 42 69 25	42 42 42 42 69 25	42 42 42 42 69 25	20 20 20 20 43 16	13 43 43 46 52 8	15 24 38 46 56 20	30 30 40 48 61 16	24 24 34 42 52 10	18 30 42 45 61 32	12 21 45 45 48 8	20 20 20 20 43 16				
Private Office with monitoring facilities (Notes 2,4)	39 39 49 65 70 10	44 44 54 70 75 10	39 39 49 65 70 10	44 44 54 70 75 10	44 44 54 70 75 10	49 49 59 75 80 10	39 39 49 65 70 10	44 44 54 70 75 10	39 39 49 65 70 10	44 44 54 70 75 10	44 44 54 70 75 10	44 44 54 70 75 10	44 44 54 70 75 10	44 44 54 70 75 10	44 44 54 70 75 10	44 44 54 70 75 10	44 44 54 70 75 10	44 44 54 70 75 10	22 22 37 49 52 8	14 41 43 46 52 8	15 24 38 46 56 20	30 30 40 48 61 16	24 24 34 42 52 10	18 30 42 45 61 32	14 17 45 45 48 8	22 22 37 49 52 8	22 22 37 49 52 8			
General office (Note 2)	44 44 44 44 64 10	49 49 49 49 69 10	44 44 44 44 64 10	49 49 49 49 69 10	49 49 49 49 69 10	54 54 54 54 74 10	44 44 44 44 64 10	49 49 49 49 69 10	44 44 44 44 64 10	49 49 49 49 69 10	49 49 49 49 69 10	49 49 49 49 69 10	49 49 49 49 69 10	49 49 49 49 69 10	49 49 49 49 69 10	49 49 49 49 69 10	49 49 49 49 69 10	49 49 49 49 69 10	27 27 27 27 45 8	19 19 19 32 42 8	7 13 29 34 46 20	22 22 27 39 51 13	16 16 26 31 41 8	10 19 33 33 51 32	19 19 19 22 38 8	27 27 27 27 45 8	27 27 27 27 45 8	19 19 19 19 34 5		
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